A STUDY OF PASSIVE SOLAR SPACE HEATING TECHNIQUES APPLIED TO FAMILY HOUSING UNITS WITHIN THE CONTINENTAL UNITED STATES

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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by

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March 1981

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A Study of Passive Solar Space Heating Techniques Applied to Family Housing Units within the Continental United States

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ABSTRACT

Passive solar energy is presented as an alternative to conventional space heating for existing and future government family housing units. The extent of the current energy problem is presented together with the implications of the findings of the Workshop on Alternative Energy Strategies. These findings significantly influence the impending energy problems facing the Department of Defense. A technical analysis is made of five passive solar space-heating design alternatives in five climate zones within the continental United States to determine the potential savings in conventional heating fuel and dollars to the Department of Defense. In addition, major advantages and disadvantages of solar energy are presented. Recommendations for the utilization of passive solar energy in family housing units conclude the thesis.

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I. INTRODUCTION

A. BACKGROUND

It is difficult today to pick up a newspaper or a magazine that does not include an article on the subject of solar energy. Articles generally present solar energy in a very positive manner, often with demonstrations of technical applications. The articles seem to indicate that a commercial solar industry is beginning to emerge.

Solar energy systems, as applied to the space heating of buildings, use the ability of the sun through active or passive methods, to provide useful heat to an interior living space. The solar space-heating systems used to accomplish this can generally be divided into two subsystems; active and passive. In an active system, the collection, storage and distribution of usable heat is accomplished by means of collectors, pumps, pipes and valves, and other complex mechanical devices. Active systems also use secondary energy sources such as electricity in order to operate. In comparison, passive solar-heating systems require no mechanical devices or secondary energy sources. The building itself provides these functions; windows collect the heat, the building itself stores the heat, and the natural laws of heat movement distribute the heat [Ref. 1]. (See Figure 1-1.)

A spectrum of active solar energy systems, ranging from solar voltaic cells to large scale steam generation plants (such as the Southern California Edison plant near Barstow, California) are under development. Unfortunately, these new solar energy systems are only in the early design stages and require a level of technology for economic operation that is not yet available. At present, new active solar systems are complex and their cost is too high to compete with conventional systems for mass installations and use [Ref. 2].

There are, however, currently available methods of harnessing the sun's energy to heat and cool buildings. With the solar space-heating technology that is now available, coupled with present-day building materials and production capabilities, it is possible to design, fabricate and construct buildings that require significantly reduced amounts of conventional fuels. Solar energy techniques provide ready means of reducing conventional consumption of residential heating fuels.

The literature on solar energy seems to imply that active solar space-heating systems are too expensive and years away from economical utilization. Active solar space-heating systems designed for residential use are not cost effective because of their required size. This situation is a result of an attempt to heat thermally inefficient structures to a comfortable interior temperature. If a structure were made

thermally efficient by means of passive solar techniques, then the active systems employed could be dramatically reduced in size, and therefore in cost, making them more economically attractive. The active energy systems currently under development offer high potentials for alleviating the probable energy crisis for the next decade [Ref. 3]. They will have an even greater effect, if the buildings they are intended to heat and cool are made more efficient by using existing and economical passive solar technology.

B. THE NEED FOR GREATER SOLAR ENERGY UTILIZATION

The Federal Government owns approximately 3.1 billion square feet of floor space in more than 490,000 buildings world wide. Within the Federal Government, the Department of Defense is the largest building owner with 395,000 buildings, totaling more than 2.4 billion square feet of floor space [Ref. 4]. The Department of Defense is also the largest single petroleum user in the United States. In fiscal year 1978, the Department consumed 170 million barrels of petroleum products within the continental United States, or approximately 2.5 percent of the total National consumption. Petroleum products represent two-thirds of the Defense Department's total energy consumption [Ref.5]. Of the Department's total petroleum usage, aircraft operations accounted for 66 percent, ship operations 15 percent, ground operations 8 percent and installation support 11 percent. (See Figure 1-2.) The installation support category, comprised primarily

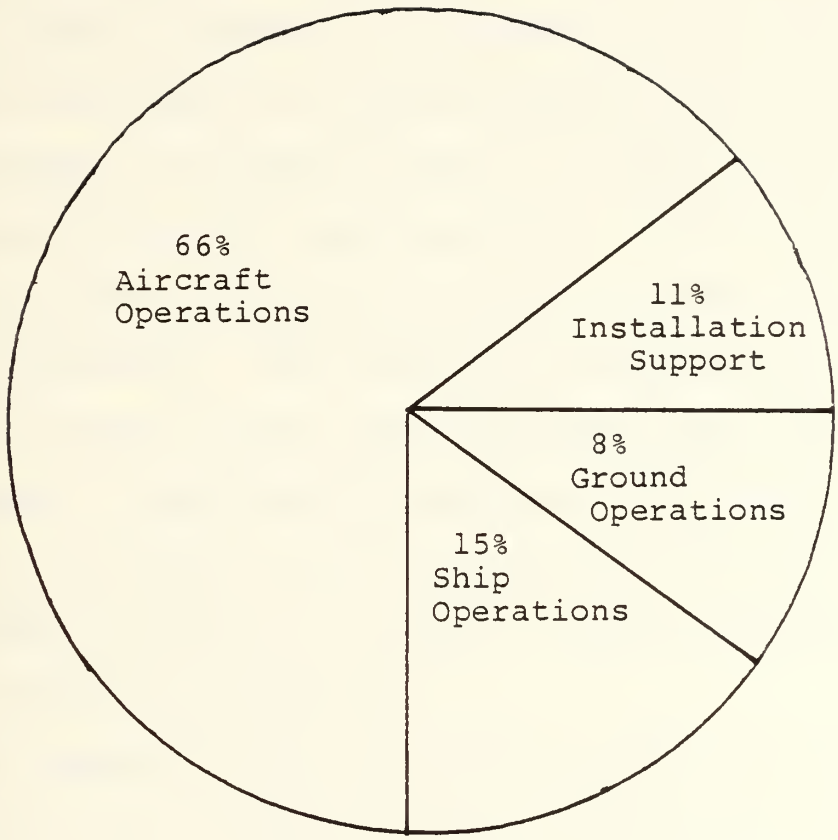


FIGURE 1-2 Department of Defense petroleum usage by operation

of buildings and facilities, includes all fuel usage not directly related to operational equipment. The category includes family housing units owned and operated by the Federal Government.

The Department of Defense manages approximately 263,000 family housing units within the continental United States which consume in excess of 40 percent of the estimated space heating and domestic hot water heating requirements within the Department of Defense [Ref. 6]. Family housing units therefore account for approximately 3 percent of the total energy consumed by the Department of Defense, or approximately 5 million barrels. This amounted to approximately $110 million dollars in 1975, the designated base year for energy management in the Federal Government. This figure is projected to increase to over $173 million dollars in 1985, a 57 percent increase in 10 years, a figure obtained from the data presented in Figure 1-3.

The proposition of this study is that, if the Department of Defense were to begin to apply proven passive solar energy techniques to its family housing units, extensive savings in fuel and overall energy costs would ensue.

C. IMPLICATIONS OF ENERGY SCARCITY TO THE DEPARTMENT OF DEFENSE

The Department of Defense is faced with the problem of finite quantities of fossil heating fuels, coupled with the rapidly increasing prices of these heating fuels (see Figure

1-3), and the steady reductions of supply and production. Because of these problems, the Department of Defense must eventually develop alternative methods of heating its family housing units so that the fuel that can be saved may be used to extend the operational life of the petroleum-powered equipment currently in inventory, and to mimimize the United States' dependence on imported energy.

The Department of Defense is responsible for providing the military force needed to deter war and to protect the security of the United States and its military allies [Ref. 4].

The Department's ability to defend the United States is dependent on energy. Every warfare system employed by the Department of Defense uses energy, and the majority are fueled by petroleum, the most critical fuel. "The most immediate military concern clearly is the assured flow of energy, particularly petroleum products, to the armed services. The United States must not be caught short in an emergency, unable to fulfill its worldwide mission. Combat readiness is an elusive abstraction interwoven with continuous training. Without training, a combat unit gradually loses proficiency, as experienced service people are replaced with recruits and moderately trained personnel. Training as a team is mandatory, as this is how the military fights. Such training demands high energy outlays. This means flying planes, driving tanks, and steaming ships" [Ref. 5].

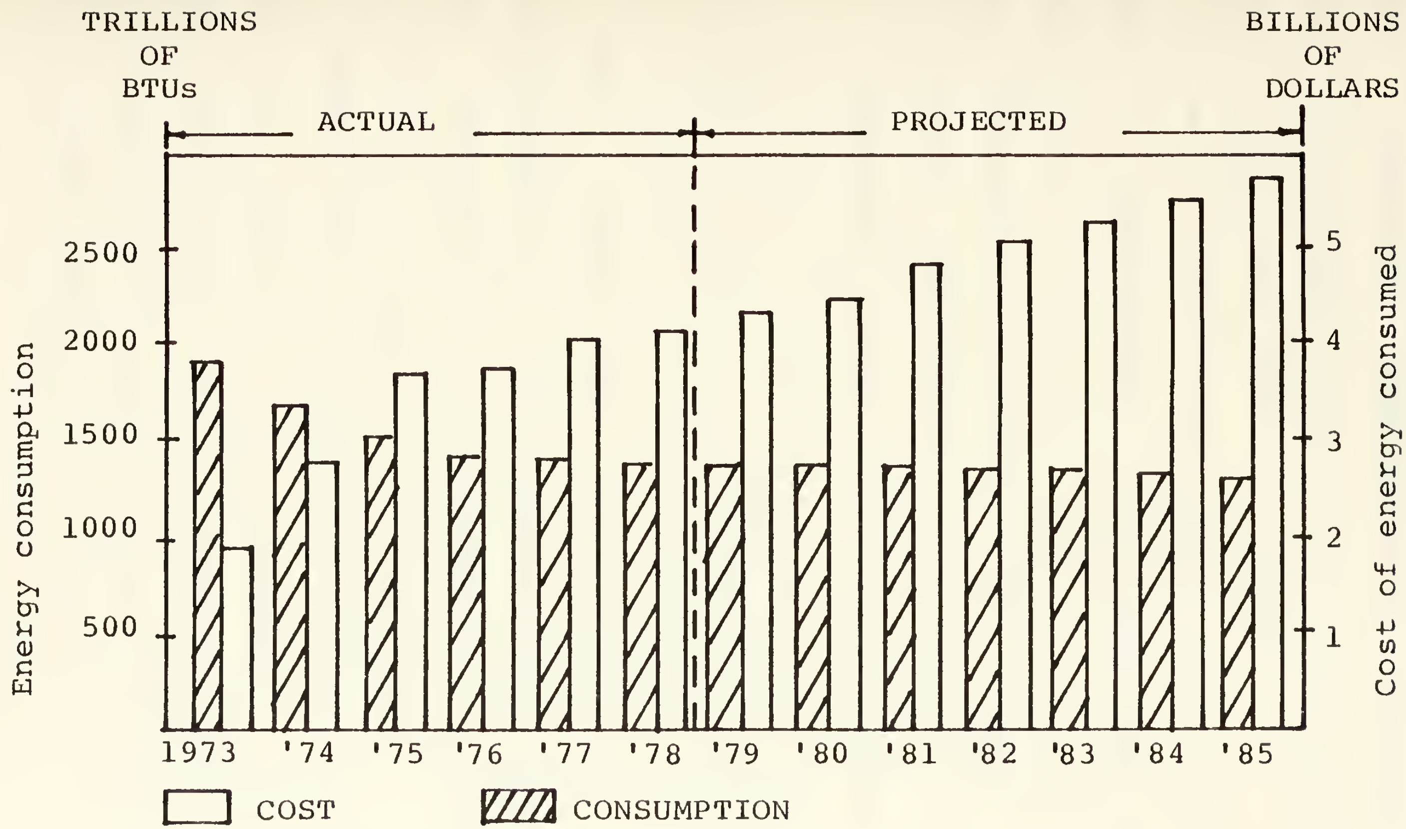


FIGURE 1-3 Department of Defense energy consumption and costs [Source: Ref. 5]

Energy can always be saved, for example, by stopping operations. If the fleets are anchored and aircraft grounded, their effectiveness, purchased and maintained at great cost, is lost. Therefore, reducing energy consumption must be accomplished without reducing the readiness and cost effectiveness of the Department of Defense.

Because oil has been employed as a political weapon against the United States by the Middle East Nations, a type of warfare sure to continue, this nation should strive for energy independence of foreign energy sources. The political and military implications of an extremely heavy dependency on imported oil and gas cannot be ignored [Ref. 1].

As the price of fossil fuels rises and the finiteness of the resource is realized, the Department of Defense may, in times of national emergency, be forced to restrict or prohibit certain energy uses. This prohibition or restriction would be reminiscent of the situations experienced during World War II. The benefits to the Department of Defense of employing passive solar space-heating techniques in family housing units within the continental United States, would be: to minimize the impact of a military energy crisis, to reduce overall energy costs, and to extend the operational life of the petroleum-powered weapons systems currently in the Department of Defense inventories [Ref. 5].

D. OBJECTIVE

The objective of this thesis is to determine if the use of passive solar techniques in government family housing units throughout the continental United States can substantially reduce the costs and fossil fuels required for conventional space heating.

E. METHOD

A literature search was undertaken on the subjects of: solar energy, passive solar technology, and alternative energy sources. Agencies and organizations that were reviewed and provided information include; the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration, and the Department of the Navy. Individual publications that were particularly noteworthy in helping to formulate the passive solar alternatives were; <u>The Passive Solar Book, Expanded Professional Edition</u>, by Edward Mazria; <u>Energy Global Prospects 1985-2000</u>, a report by the Workshop on Alternative Energy Strategies, and <u>All Through the House, A Guide to Home Weatherization</u>, by Thomas Blandy and Denis Lamoureux.

The literature reviewed indicated a lack of scientific data on passive solar techniques. Of particular concern was the absence of large scale passive feasibility studies. Additionally, it was extremely difficult to obtain accurate energy-use data from the Federal Government. A report from the Department of Energy addressed the subject. "Repeated

attempts were made during the preparation of this report to arrive at reasonable estimates of average annual energy-use per square foot for the 18 major energy-using agencies. The magnitude of the data problem was so great that each attempt failed to yield a set of numbers in which confidence could be placed" [Ref. 4].

To determine the potential savings of fuel (and therefore dollars) to the Department of Defense for using passive solar energy as a viable alternative to conventional space-heating systems, five passive space-heating alternatives were formulated and analyzed, a heat gain/heat loss analysis was used to determine how much solar energy was available from the five passive solar space-heating design alternatives in five climate zones within the continental United States. The analysis was conducted by means of a hypothetical single family unit reflecting median characteristics of family housing units located within the continental United States. The evaluation of the passive solar potential for each alternative was determined by heat loss/heat gain comparisons at an interior temperature of 65°F. Based on heat loss/heat gain figures and life cycle cost calculations, conclusions and recommendations were formulated.

F. THESIS ORGANIZATION

Chapter I introduces the reader to the problem of energy consumption and costs faced by the Department of Defense in heating family housing units within the continental United States.

Chapter II discusses the current energy outlook and the implications of the findings of the Workshop on Alternative Energy Strategies as they pertain to the impending energy problem facing the Department of Defense.

Chapter III discusses the principles of passive design and presents brief definitions of heat transfer techniques within a passive solar design. Essential features and elements of passive design are discussed.

Chapter IV looks at five passive solar space-heating alternatives and analyzes them for their passive solar potentials in five climate zones within the continental United States. A hypothetical single-family unit, reflecting median characteristics of family housing units within the continental United States, is used in the analysis. The evaluation of the solar heating potential of each alternative is determined by heat loss/heat gain and life cycle cost evaluations.

Chapter V presents a number of significant advantages and disadvantages of solar energy to the Department of Defense.

Chapter VI summarizes the major conclusions reached in this thesis and concludes with recommendations for the utilization of passive solar energy in family housing units.

II. ENERGY OUTLOOK

A. GENERAL

This chapter presents an overview of the state of the current energy availability situation faced by the Department of Defense. Several viewpoints on the availability of fossil fuels for the next century are presented from private and public sources. They circumscribe some of the problems that the Department of Defense may face unless alternate energy sources are identified.

The successful utilization of energy has been an essential component of man's ability to survive and develop socially. A characteristic energy statistic about the United States is that with slightly over 6 percent of the world's population, the United States consumes nearly 33 percent of the world's total energy output [Ref. 7]. Because of this fact it is time to evaluate the United States' prodigal use of energy and its pervasive role in our society. Two major factors dictate the pervasion of energy: (1) the availability of sufficient resources and (2) the technology to convert the resources to useful heat and work. The fact that fossil fuels are finite was always known, but the world believed them to be virtually inexhaustible. The United States has recently been dramatically reminded of the fact that, as a result of the 1973 oil embargo, not only are the

reserves of fossil fuels (oil, coal, natural gas) finite, but the era of low cost, easily obtainable fossil fuels has ended.

The dramatic growth since World War II in the rate of consumption of these fossil fuels both in the United States and throughout the world is a cause for alarm.

Since World War II the United States, specifically the Department of Defense, has had the ability to shift or reallocate energy reserves whenever the need arose, particularly when National defense was an issue [Ref. 5]. But the ability to shift energy reserves may not be available in the future if the predictions and outlooks for the exhaustion of fossil fuels are realized.

Information obtained from a report by the Exxon Corporation indicated that for consumers, energy in the future will cost a good deal more than it has historically. Even the discovery and development of remaining conventional oil reserves will incur much higher costs. Compared to the past, future oil discoveries are likely to be smaller, at greater depths, in more physically hostile environments, and at locations more remote from markets.

World energy demand, currently about 100 million barrels of oil equivalent per day, is expected to grow at a rate of 2-1/2 percent per year from 1978 to the year 2000, compared with the 5-1/2 percent per year increase from 1965-1978.

This slower rate is associated with slower economic growth and less energy intensity. Nonetheless, world energy demands are projected to reach 130 million barrels of oil equivalent per day, by the year 1990 and to exceed 160 million barrels per day by the year 2000. This represents an increase over the 1978 levels of about one-third by 1990 and two-thirds by 2000 [Ref. 8].

Crude oil is projected to remain the largest single source of supply for meeting world energy demand. Over the period to the year 2000 its availability will necessarily depend on the rate of discovery of new reserves. Since 1930, oil discovery rates have ranged from less than 10 to more than 25 billion barrels per year. Prior to 1970, discovery rates were well in excess of production, so the world's inventory of discovered reserves was increasing. Since the early 1970's, a decline in oil discoveries and a continuing rise in oil consumption have reversed this situation. As a result, the inventory of discovered reserves has now begun to decline. This pattern is expected to continue, despite a projected growth rate for oil consumption of less than one percent per year and assumed aggressive efforts to accelerate discoveries.

The world's remaining conventional oil resources are assessed to be in the range of 1 to 1-1/2 trillion barrels. This number includes oil which has yet to be discovered.

Consequently, even with a very active exploration effort, the average discovery rate for the period of 1978 to 2000 is likely to be well below the expected production rate of about 20 billion barrels per year. The unavoidable result will be a further decline in the world's inventory of discovered reserves. Production cannot continue growing under these circumstances, and it is reasonable to expect it to level off slightly above 20 billion barrels per day around the turn of the century [Ref. 8].

Figure 2-1 contrasts the relative amounts of various energy sources currently known to be available and economically recoverable with existing technology, with the consumption pattern of those energy sources. With the exception of coal, the United States consumes a significantly larger percentage of a particular energy source than the percent of that energy source that is known to exist as a proven reserve.

George Marienthal, Deputy Assistant Secretary of Defense for Energy, Environment and Safety, provides a sobering scenario of the future if present energy consumption trends are not controlled and substantially modified.

> "The end of oil will not, of course, come with a bang. It will be more like the Chinese water torture than the guillotine. With every passing year there will be less oil available for the consumer. Prices will rise inexorably. Everything which is tied to energy will increase in cost as the cost of energy climbs. In a modern industrial society it is hard to imagine many goods or services which are not inextricably linked to energy. The poor will be the first

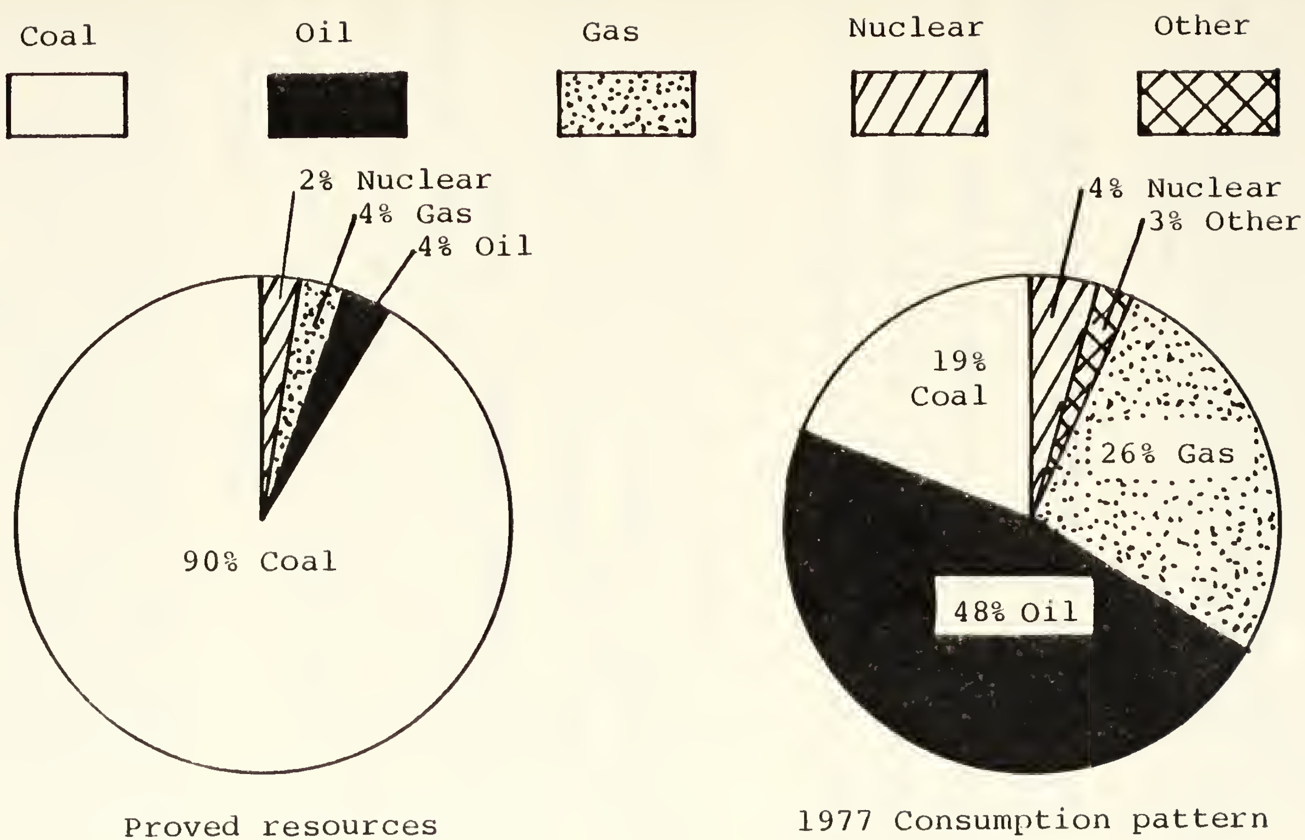


FIGURE 2-1 Relationships between Consumption patterns and reserves for the United States

[Source: Ref. 9]

affected. Poor nations, with low foreign exchange reserves but a desperate need for capital, will be forced to revert to a pre-industrial society. Poor people in the developed nations will find it impossible to afford to drive a car, heat their homes comfortably in winter, or cool them in summer. As the situation worsens, small business will fail, large industries with high energy needs will be hard pressed to stay solvent, suburbs which are not served by mass transit will wither, cities will become much more crowded and recreation which is energy intensive will disappear for all but the super rich" [Ref. 5].

B. CONCLUSIONS FROM THE WORKSHOP ON ALTERNATIVE ENERGY STRATEGIES

Countless energy scenarios, charts and computer models have been developed during the past decade that estimate the amounts and availability of fossil fuels now and in the future.

Of the reports that were evaluated by the author, the report of the Workshop on Alternative Energy Strategies, a project sponsored by the Massachusetts Institute of Technology, titled Energy: Global Prospects 1985-2000 was the most complete and explicit. The following are some of the conclusions from that study, which may significantly affect the way energy is utilized by the Department of Defense in the next decade.

"After two years of study we concluded that world oil production is likely to level off--perhaps as early as 1985--and that alternative fuels will have to meet growing energy demand. Large investments and long lead times are required to produce these fuels on a scale large enough to fill the prospective shortages of oil, the fuel that now furnishes most of the worlds' energy. The task of the world will be to

manage a transition from dependence on oil to greater reliance on other fossil fuels, nuclear energy and, later, renewable energy systems. Our major conclusions are as follows:

(1) The supply of oil will fail to meet increasing demand before the year 2000, most probably between 1985 and 1995, even if energy prices rise 50% above current levels in real terms. Additional constraints on oil production will hasten this shortage, thereby reducing the time available for action on alternatives.

(2) Demand for energy will continue to grow even if governments adopt vigorous policies to conserve energy. This growth must increasingly be satisfied by energy resources other than oil, which will be progressively reserved for uses that only oil can satisfy.

(3) The continued growth of energy demand requires that energy resources be developed with the utmost vigor. The change from a world economy dominated by oil must start now. The alternatives require 5 to 15 years to develop, and the need for replacement fuels will increase rapidly as the last decade of the century is approached.

(4) Electricity from nuclear power is capable of making an important contribution to the global energy supply although worldwide acceptance of it on a sufficiently large scale has yet to be established. Fusion power will not be significant before the year 2000.

(5) Coal has the potential to contribute substantially to future energy supplies. Coal reserves are abundant, but taking advantage of them requires an active program of development by both producers and consumers.

(6) Natural gas reserves are large enough to meet projected demand provided the incentives are sufficient to encourage the development of extensive and costly intercontinental gas transportation systems.

(7) Although the resources base of other fossil fuels such as oil sands, heavy oil, and oil shale is very large, they are likely to supply only small amounts of energy before the year 2000.

(8) Other than hydroelectric power, renewable resources or energy--e.g., solar, wind power, wave power--are unlikely to contribute significant quantities of additional energy during this century at the global level, although they could be of importance in particular areas. They are likely to become increasingly important in the 21st century.

(9) Energy efficiency improvements, beyond the substantial energy conservation assumptions already built into our analysis, can further reduce energy demand and narrow the prospective gaps between energy demand and supply. Policies for achieving energy conservation should continue to be elements of all future energy strategies.

(10) The critical interdependence of nations in the energy field requires an unprecedented degree of international collaboration in the future. In addition, it requires the will to mobilize finance, labor, research and ingenuity with a common purpose never before attained in time of peace; and it requires it now.

Failure to recognize the importance and validity of these findings and to take appropriate and timely action will almost certainly result in a world different from the one which these projections have been based. Failure to act could lead to substantially higher energy prices as the supply/demand imbalance becomes more apparent--with the depressant side effects on the economies of the world and consequent frustration of the aspirations of the less developed countries. The major political and social difficulties that might arise could cause energy to become a focus for confrontation and conflict.

In addition, the longer the world delays facing the issue, the more serious the outcome will be. Even with prompt action the margin between success and failure in the 1985-2000 period is slim. Time has become one of the most precious of our resources. Recognizing the importance of time and the need to respond can help us through the period of transition that lies ahead" [Ref. 3].

A report published by Tetra Tech. Inc. projected figures for the exhaustion dates of fossil fuels that do not share the same optimistic outlooks for petroleum resources.

"Theoretical world oil exhaustion dates are calculated for the resources boundaries as a proxy for depletion dates. The ultimate depletion date is when the amount of available resource falls below that required to maintain current consumption patterns. Specifically, depletion dates (or transition periods) are determined by world oil production, consumption, and pricing policies, and by ultimately discovered recoverable resources. The calculation assumes that sufficient oil is produced and available to meet the demand. In actual practice, production will decline as the reserves are used, thereby delaying the actual exhaustion date by creating a supply shortfall (that is, depletion). Calculating theoretical exhaustion dates indicates the length of time until oil supplies are exhausted.

Three alternative oil consumptions growth rates are used to project world exhaustion dates. If the conservative 2.5 percent annual consumption growth rate is assumed, the entire estimated range of recoverable resources would be exhausted between 2017 and 2025. Using the historical growth rate of 7 percent, exhaustion would occur sometime between 2003 and 2007. In the unrealistic and optimistic case of no increase in consumption, exhaustion would occur by 2070" [Ref. 1]. (See Figure 2-2.)

From the literature reviewed, and the energy outlooks presented, it can be concluded that fossil fuels are rapidly being depleted. Unless this rate of depletion is slowed, the exhaustion of ultimately recoverable petroleum resources may occur as early as the year 2000.

A review of current newspaper articles suggests that the United States is currently experiencing the beginnings of the major predictions that the Workshop on Alternative Energy Strategies presented.

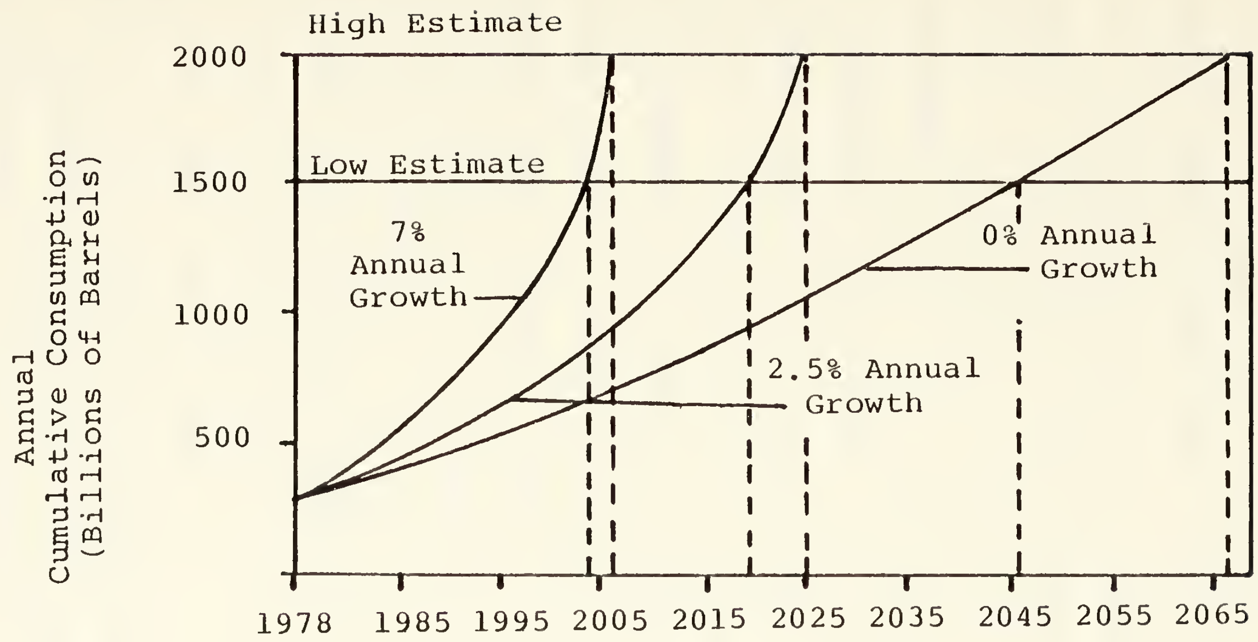


FIGURE 2-2 Projected world exhaustion dates of ultimately recoverable petroleum resources

[Source: Reg. 1]

C. ENERGY SOURCE ALTERNATIVES

The United States now imports approximately 7 million barrels of oil daily, compared with the total daily consumption of 17 million barrels. This means that the United States will remain dangerously vulnerable to a cutoff of oil imports during the next ten years. Currently the United States has 91 million barrels of oil stockpiled in huge salt domes located along the Gulf coast of Texas and Louisiana whose capacity is estimated at 250 million barrels [Ref. 1].

The continuing wars in Iran and Afghanistan are doing more than threatening world peace. The implied uncertainty over the future flow of oil supplies from the Persian Gulf has touched off a renewed interest in offshore oil exploration and oil stockpiling throughout the world. In addition, some 24 million acres of Federal lands off the California coast from the Oregon border to Mexico have been opened to oil and gas exploration by the Bureau of Land Management. The United States Geological Survey estimates that the total offshore coastal area contains undiscovered resources totaling 3.5 billion to 10.9 billion barrels of oil and 5.4 trillion to 15 trillion cubic feet of gas.

According to the President's Commission on Coal, the price of a barrel of oil from the OPEC countries has risen from $3.47 per barrel in 1973 to $14.55 a barrel in January 1980. Because of this rapid increase in price, there is a

rapidly expanding demand for a petroleum substitute that is both affordable and plentiful. Coal fills both requirements, according to a recent World Coal Study directed by Carroll L. Wilson of the Massachusetts Institute of Technology. It is estimated that the World's technically and economically recoverable coal reserves would last about 250 years at the 1977 rate of production--2.5 billion tons. The President's Commission on Coal further stated that the United States is the "Saudi Arabia of Coal." Coal is the world's most abundant fuel, and more than one quarter of it lies under American soil. More than 1.7 trillion tons have been mapped by the United States Geological Survey, which estimates a similar quantity has yet to be discovered. With recoverable reserves of 440 billion tons, America has a supply that could last more than 100 years, even with stepped up production rates. Economists predict that because coal costs just over one-fourth the price of oil in equivalent energy, many nation's demand for coal could rise 500 percent over the next decade. The demand for coal will increase dramatically because it makes good economic sense to use it. The World Coal Study concluded that coal will have to supply between half to two-thirds of the world's energy needs by the year 2000, compared to 25 percent now. That increase can take place if the United States becomes part of greatly expanded international coal trading [Ref. 10].

For each of the known sources of energy, there is a drawback. Petroleum is limited, and the cost is high and will continue to escalate exponentially. Nuclear energy is enormously expensive and is fraught with political opposition, based on fears for safety in the wake of Three Mile Island and other episodes. Coal is available and abundant, but burning certain types of it causes environmental problems and may be producing the greenhouse effect that scientists fear will alter the temperature of the globe and might ultimately melt the polar ice caps, causing widespread flooding of coastal areas.

According to George Marienthal, Deputy Assistant Secretary of Defense for Energy, Environment and Safety, "Solar energy is not yet cost effective in most areas, except for hot water heating and a handful of experimental projects sponsored by the United States Government and large utility companies. Further, retro-fit projects on existing buildings require a substantial capital outlay. ...Fusion, which has great promise for a non-polluting, renewable source, is several decades away from commercial use, in the judgement of most knowledgeable people. In addition to technical development issues, the fusion process also demands prodigious amounts of capital. Hydro-electric power can still be developed in some areas of the country but for each river to be dammed, we lose some irreplaceable scenic area, and environmentalists are strongly opposed to further dam building. Wind power has

advocates in certain areas where wind blows steadily, but it cannot be widely used, since in most areas, wind is too sporadic to justify the investment" [Ref. 5].

Alternative energy sources such as; nuclear fission, nuclear fusion, and active solar space heating are enormously expensive, hydro-electric power and wind power have limited potential, and a major shift to coal as a primary energy source is presently under way. These alternative energy sources when fully developed, will provide energy reserves from which the Department of Defense will be able to draw. Until this occurs, additional energy sources capable of reducing current energy consumption must be employed. One of the proposals to help resolve the problem of reducing energy consumption for the Department of Defense is to use passive solar space-heating techniques in family housing units throughout the continental United States. The subsequent chapters in this thesis will explore the extent to which this proposal can help reduce the energy consumption of the Department of Defense.

III. PRINCIPLES OF PASSIVE SOLAR DESIGN

Chapter III will present the principles of heat movement as they apply to passive solar space-heating designs. The essential elements that make up a passive design will be discussed as well as the concepts of direct gain, indirect gain, and isolated gain. These concepts and elements will be looked at in terms of their relationship between the sun, heat storage, and the living space.

The principles of passive solar design are not new. The early Greeks and Romans used them to heat their villas and public baths. The Indians of the American Southwest used them in locating and building their pueblos. The New England farmhouse and the Victorian houses of the 19th century all used the principles of passive solar design. In fact, current passive solar design is merely a new approach, using modern construction materials and techniques, to an old basic technology [Ref. 11, 13].

A. HEAT TRANSFER CONSIDERATIONS

Passive solar heating systems require no mechanical devices or secondary energy sources in order to operate [Ref. 2]. To appreciate how passive designs function, it is important to understand the principles of the movement of heat.

Heat travels three basic ways; through radiation, conduction and convection.

Radiation transmits heat through electromagnetic waves that travel from a warmer object to a cooler one without heating the space in between. The prime example of radiative heat movement is the sun, a warm object which radiates its heat to the cooler earth. In home space conditioning, radiation begins or ends with the outer skin of the building; conduction carries the heat through the walls and ceiling.

Conduction occurs when heat moves through a solid material by passing from molecule to molecule. A home loses warmth in the winter by conducting the heat through its walls and roof to the outside. During the summer, the process is reversed when heat from the outside moves in through the walls and ceiling to raise the interior temperature of the house. Insulation added between the walls and ceiling spaces slows the conduction process.

Convection takes place through the movement of air or liquid. Convection is an important means of distributing collected heat in the house. An attached solar greenhouse system, for example, uses the natural air currents created by the heating and cooling of air to deliver warm air into living spaces while drawing unwanted cold air out.

Successful passive solar design depends on controlling the natural tendencies of heat and using them to the best advantage [Ref. 7]. The principles are the same for capturing heat and maintaining its warmth in the winter, or

rejecting heat to maintain coolness during the summer. These characteristics of heat explain why such simple techniques as adding double-glazed windows, insulating, shading glass, or incorporating thermal mass can make such a big difference in keeping a home at a comfortable temperature.

A building designed to work with nature will be warmer in the winter, and cooler than the outside temperature in the summer, without using additional energy or equipment for space conditioning. This is passive design. It works by putting the natural heating properties and cooling potential of the sun to work, and using the structure itself to perform solar collection, storage and distribution [Ref. 11].

There are three essential features of true passive design:

1. Large areas of south facing glass to let in warmth of the winter sun.

2. A solid, massive element such as a concrete floor or wall in line with the windows to absorb the heat and radiate it back into the building when needed.

3. Shading on the east, west, and south windows to help keep the building cool in summer.

The first step in passive solar design is to face the building due south. The next is to add a large overhang on the south to shade the windows from the summer sun. Since the sun is higher in the sky in summer, a properly constructed overhang still allows the lower rays of the winter sun into

the building when their heat is needed most. Deciduous shade trees planted on the south side of the building also provide shade during summer and let sunlight through during winter after they lose their leaves [Ref. 2]. The solid, massive features to hold the sun's warmth may be a concrete slab floor, a water-filled tank, a wall of concrete or masonry, a stand of tall metal tubes or barrels filled with water. The mass may be part of the southern wall of the building or included in a south-facing greenhouse addition. During the day, the sunlight must shine directly on the mass, so it absorbs enough heat to warm the building at night. It is important to insulate the windows at night by closing curtains or shutters, to insure that the heat stays in the building and does not flow back outside. The process can be reversed during summer, to help keep the building cool. If the building is open during the night, the mass will release the heat absorbed from the structure during the day to the cool night air by radiation. Blinds and shades keep out the heat of the day, and the lower temperatures of the mass will help maintain a comfortable range inside [Ref. 11].

In buildings designed to work with nature, the heat moves by itself, without the use of pumps and fans. People who live in homes heated by a passive solar system feel more comfortable at lower temperatures in winter, because the structure itself has warmth, not just the air within it.

Properly done, passive solar design can meet 50-60 percent of a building's heating needs. In some cases, as in the double-shell house, that percentage may rise to over 90 percent [Ref. 12].

B. ELEMENTS OF PASSIVE SOLAR DESIGN

The first element of a solar heating system is the collector. Sunlight falls on the collector and heats it. The heated collector in turn raises the temperature of the transfer medium inside it, either a liquid or a gas, which carries the heat to storage. Storage, the second element of solar heating, is where the heat is held for later use at night or on cloudy days. The distribution system is the third element, it delivers the heat to where it is neded.

In an active solar heating system, these functional elements are separate pieces of equipment that are physically removed from the living space. In passive solar design, glass windows and doors collect the sun's heat; thermal mass stores the heat; and the natural laws of heat movement distribute the heat. A modern passive home must be designed to work with its surroundings to provide comfortable temperatures year round. Although the principles of passive design are simple and can be executed with common building materials and construction skills, passive solar systems must be carefully designed.

Passive space conditioning techniques are perhaps the most cost effective way to realize the full potential of solar energy [Ref. 13]. Many of the materials required for a passive building are the same as for a conventional structure. The additional costs of a passive home are less than they would be if an active solar system had been incorporated into a similar design. Any added costs of a passive structure can usually be offset by lower operating costs or less complex backup equipment.

C. CONCEPTS OF PASSIVE SOLAR DESIGN

In order to establish a framework for understanding passive systems, three concepts need to be defined: direct gain, indirect gain and isolated gain. Each explains the relationship between the sun, heat storage and living space. Within each of these categories, it is possible to identify various systems.

The first and simplest approach to passive solar heating is the concept of <u>direct gain</u> [Ref. 2]. Simply defined, the actual living space is directly heated by sunlight. Sunlight passing through the large expanse of south facing glass heats the air, whicn in turn heats the walls, floors, and strategically located thermal masses. Floors of tile, brick, concrete, and thick walls of adobe, concrete or water columns, individually or in combinations, provide thermal storage. With the direct gain approach the space becomes a

live-in solar collector, heat storage and distribution system all in one. At night, movable insulation is placed on the windows to retain the heat collected during the day. In summer, the process is reversed and heat is allowed to escape through open windows and vents.

Another approach to passive solar heating is the concept of indirect gain, where sunlight first strikes a thermal mass which is located between the sun and the space. The sunlight absorbed by the mass is converted to thermal energy and then transferred into the living space. The thermal wall works by absorbing sunlight on its outer face and then transferring this heat through the wall by conduction. Heat conducted through the wall is then distributed to the space by radiation and to some degree by convection.

An attached greenhouse is essentially a combination of direct and indirect gain systems. Constructed on the south side of a building with a mass wall separating the greenhouse from the building, a solar greenhouse can create an attractive border between the living space and the outdoors. The greenhouse also establishes a thermal buffer zone which can substantially reduce heat losses by reducing air infiltration into the building. Since it is directly heated by sunlight, the greenhouse functions as a direct gain system. However, the space adjacent to it receives its heat from the mass wall. Sunlight shines through the greenhouse windows and heats the

thermal mass inside. This mass can be water in barrels or tanks, masonry walls, rocks, concrete or other massive materials. Warm air collected in the greenhouse is transferred to the house by openings located on the shared wall of the greenhouse and the main house.

A third approach to passive solar heating is the concept of <u>isolated gain</u>. In principle, solar collection and thermal storage are isolated from the living spaces. This relationship allows the system to function independently of the building, with heat drawn from the system only when needed. A common application of this concept is the natural convective loop which is found in the double-shell house.

Chapter III presented the principles of heat movement, radiation, convection, and conduction, as they apply to passive solar designs. The concepts of direct gain, indirect gain, and isolated gain were presented as well as examples of each.

In chapter IV the concepts and elements of passive solar space heating are applied to Government family housing units within the continental United States. Five passive heating alternatives will be used to determine the potential savings in conventional heating fuel and dollars to the Department of Defense.

IV. ANALYSIS OF POTENTIAL SAVINGS

Chapter IV applies the elements and concepts of passive solar space heating to five passive design alternatives to government family housing units within the continental United States. This will be done to determine the potential svaings in conventional heating fuels and dollars to the Department of Defense over a 25-year economical life of family housing units. Total life cycle costs, as well as life cycle fuel cost comparisons will be used to indicate the relative savings to the Department of Defense.

A. METHOD OF ANALYSIS

An inventory of family housing units within the continental United States was performed to determine the number of units located within each of the states. These figures are shown in Figure 4-1. From the inventory data that was obtained, a hypothetical family housing was formulated which reflected the median characteristics of all family housing units located within the continental United States. Design characteristics of a family housing unit and design assumptions used in the analysis are provided in Appendix A.

The United States was then segmented into five climate zones whose boundaries are shown in Figure 4-2. These zones were selected along average solar radiation intensity lines. Several cities were selected in each zone whose climatic

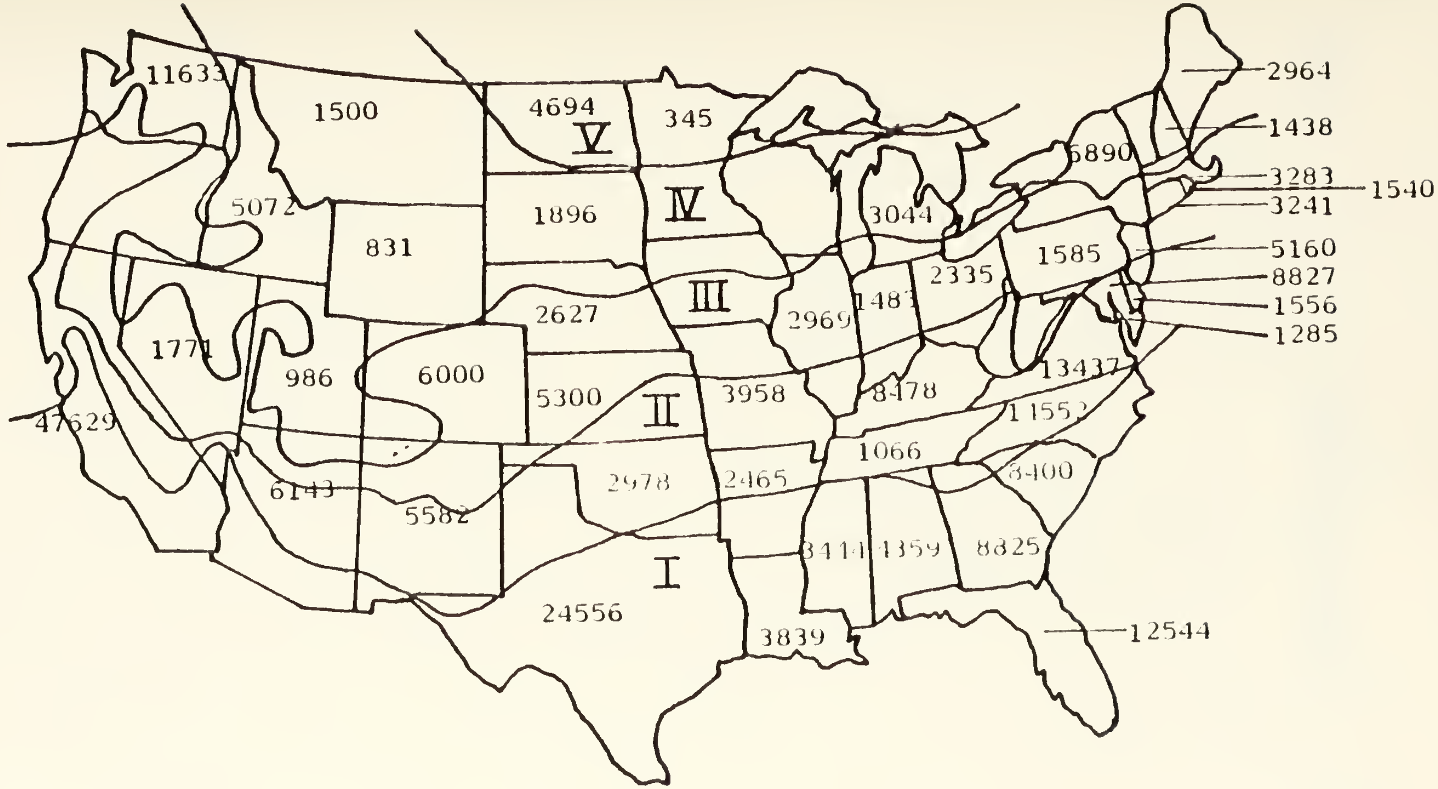


FIGURE 4-1 Total number of family housing units by state
[Source: Ref. 14]

TABLE 4-1 Total number of family housing units by climate zone

Zone		Number of Units	Percentage of Total Units
1		113,596	43.27
2		70,327	26.80
3		48,927	18.64
4		24,621	9.37
5		5,039	1.92
	Total	262,510	100

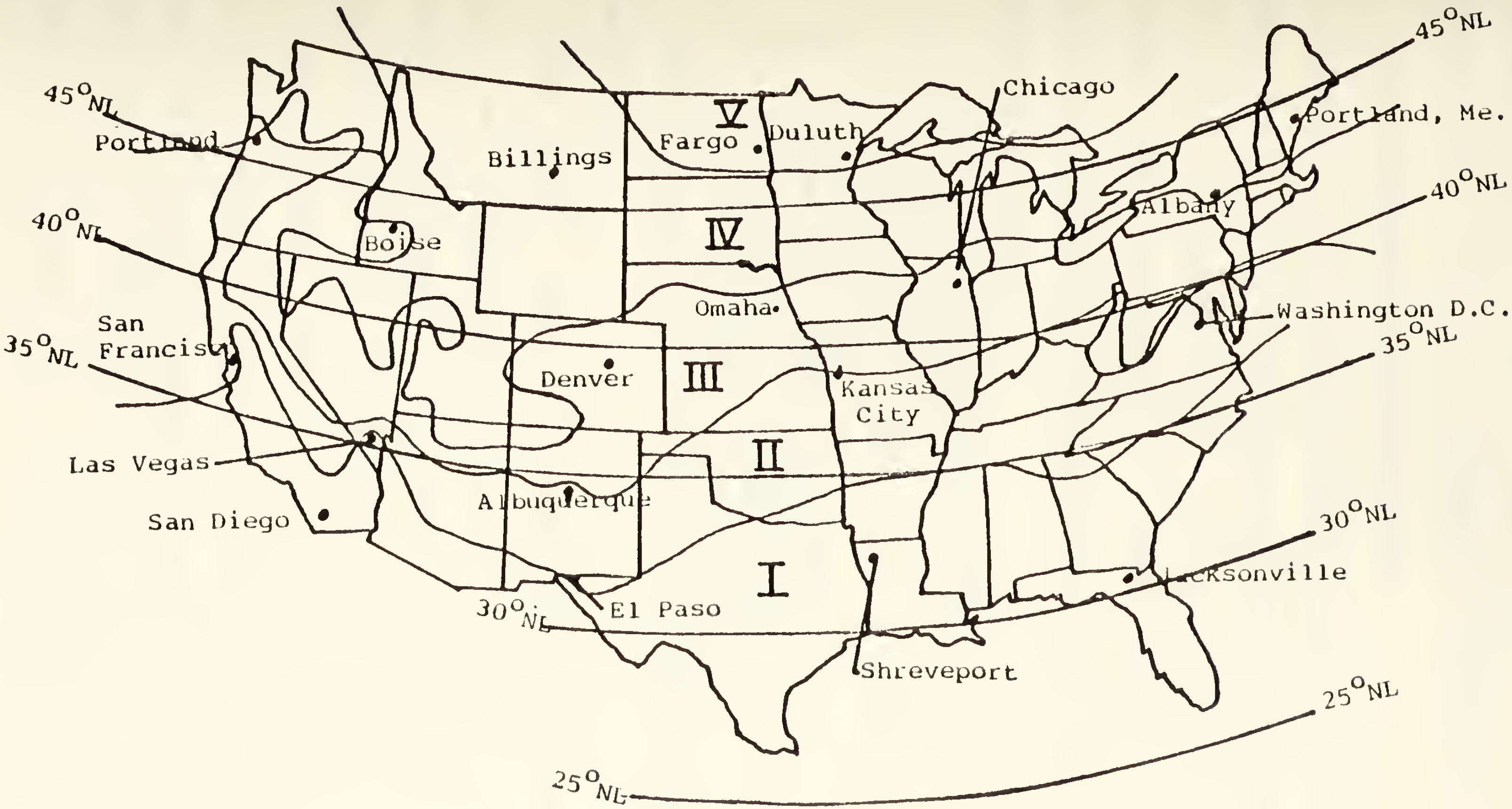


FIGURE 4-2   Climate zone map

[Source: Ref. 15]

conditions were typical of that zone. The solar and climatological data was then obtained for each of the cities. Climatological data is presented in Appendix B.

B. SOLAR POTENTIAL DETERMINATION

Because actual measured space-heating load data for family housing units was not available, the heat loss and heat gain requirements were manually computed for the theoretical family housing unit as well as for the five passive design alternatives. The pertinent data required for the calculations were:

1. Monthly heating degree days
2. Incident solar radiation per month
3. Average wind velocity
4. Exterior walls, roof and floor composition and area
5. Window and glass area
6. Number of doors and windows
7. Underground floor composition
8. Interior design temperature
9. Infiltration/ventilation rate.

Sample heat gain/heat loss calculations are provided in Appendix C.

Five passive design alternatives were formulated incorporating the principles and elements of passive solar space-heating. The analysis consisted of examining each of the five design alternatives in each of the five climate zones at an interior design temperature of 65°F to determine the amount of heat loss and the amount of heat gain available. Life cycle costs were calculated to reflect fuel cost savings and additionally for break-even points for the various alternatives. Life cycle cost data is provided in Table 4-3.

C. ALTERNATIVES

1. Alternative no. 1 - do nothing

This alternative reflected the current heating state of a representative three-bedroom single-family unit in government family housing located in each of the five climate zones throughout the continental United States. Alternative no. 1 was used as the comparative control alternative for each of the other four alternatives.

2. Alternative no. 2 - southern exposure

This alternative examined the same structure used in alternative no. 1 but oriented it toward maximum southern exposure.

3. Alternative no. 3 - direct gain system

The direct gain system is the simplest approach to passive solar heating, the actual living space is directly heated by sunlight. To do this, it must contain a method of absorbing and storing enough daylight heat to release at night, thereby maintaining a reasonable temperature variation. The method used in passive solar design to accomplish this goal is to provide a sufficient expanse of south facing glass and enough thermal mass, strategically located in the living space, to absorb and store the available solar energy. In alternative 3, the area of south facing glass was increased by 50% over alternative no. 2.

4. Alternative no. 4 - super insulation

This alternative looked at the same representative house that was examined in alternative no. 2, but with the thickness of the insulation in the roof and walls increased to a value of R-43, and with triple glazed windows. In addition, overall infiltration amounts were reduced by 50 percent.

5. Alternative no. 5 - double-shell house (Figure 4-3)

This alternative looked at the newest of the passive heating techniques, the double-shell house. The double-shell house is basically a house within a house. The living space or inner house is surrounded on four of its six sides (north and south walls, roof and floor) by an airspace. The airspace is, in turn, enclosed by an outer shell consisting of a roof, north and south walls, and exposed earth underneath the floor. The east and west walls are single walls that span both the inner living area and the airspace [Ref. 16]. The south wall, which is glazed at approximately 50 percent of its surface area, is substantially set off from the inner wall to form a greenhouse space on the entire southern exposure of the house. The house heats itself by means of a convective loop which circles in the airspace between the two shells. Air heated by the sun in the greenhouse space rises over the inner house and down between the two north walls and under the house, where it heats up a thermal mass to be used for nighttime heating. Examples of

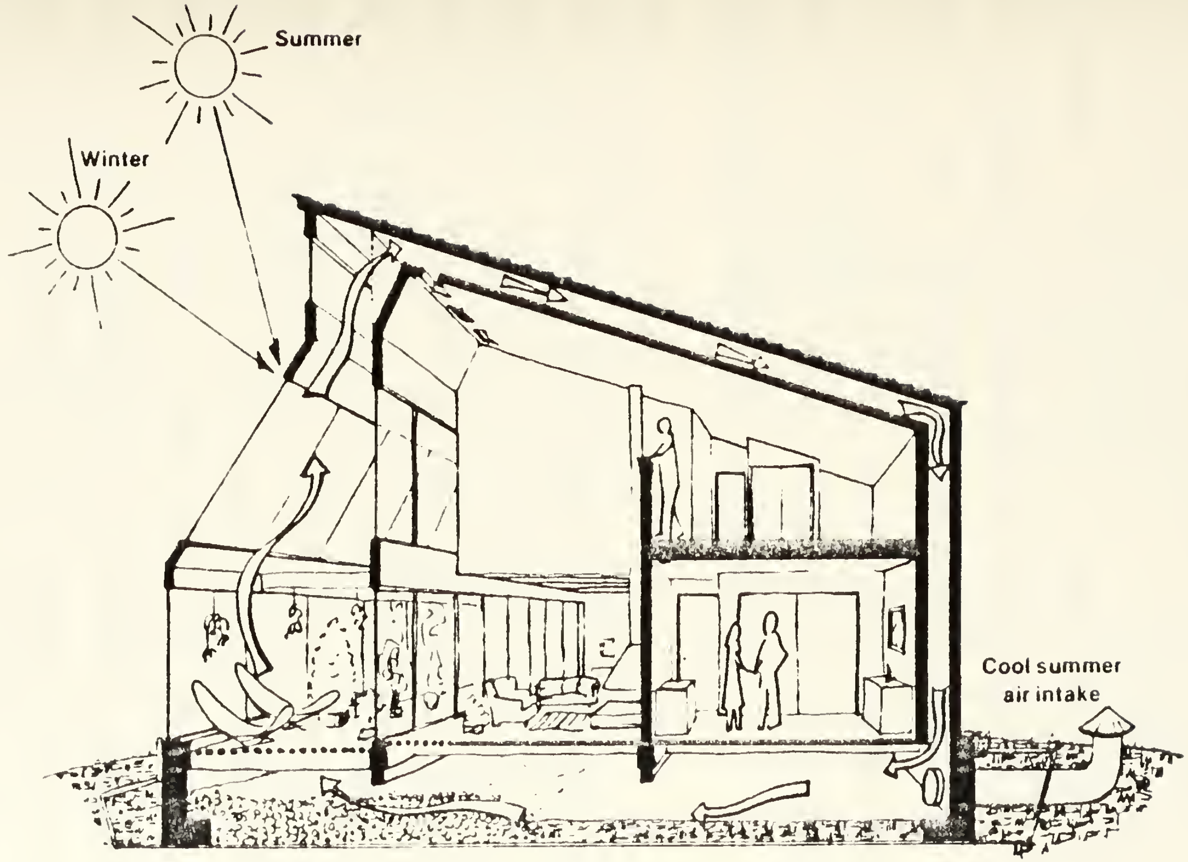


FIGURE 4-3 The Kubota/Smith house
Built in California's Sierra Nevadas, provides up to 90% of its heat through passive solar means.

[Source: Ref. 12]

passive space-heating design alternatives are shown in Figure 4-4.

D. CRITERIA FOR DETERMINING DESIGN ALTERNATIVE EFFECTIVENESS

The criteria that was used for this analysis was to fix the effectiveness of the model by fixing the interior temperature at 65°F. This was done for each of the alternatives in order to determine the amount of auxillary space heating required. This resulted in the lowest possible space-heating cost for each alternative. In order to determine the most effective alternative that would meet the established criteria, an effectiveness model was formulated.

E. EFFECTIVENESS MODEL

The effectiveness model that was formulated is as follows: Effectiveness, which was measured by the amount of auxillary conventional heat required, was equal to the total heat loss of the house, minus the total solar heat gain of the house. To enhance the workability of the model it was necessary to expand it as follows: heat gain was determined to be a function of (1) the sun's azimuth and altitude, (2) the building site orientation (the degree of southern exposure), (3) the square footage of exterior wall exposure, and (4) the square footage and tilt angle of glass with southern exposure. Heat loss was determined to be a function of: (1) the square footage of walls, floors and ceilings; (2) the overall

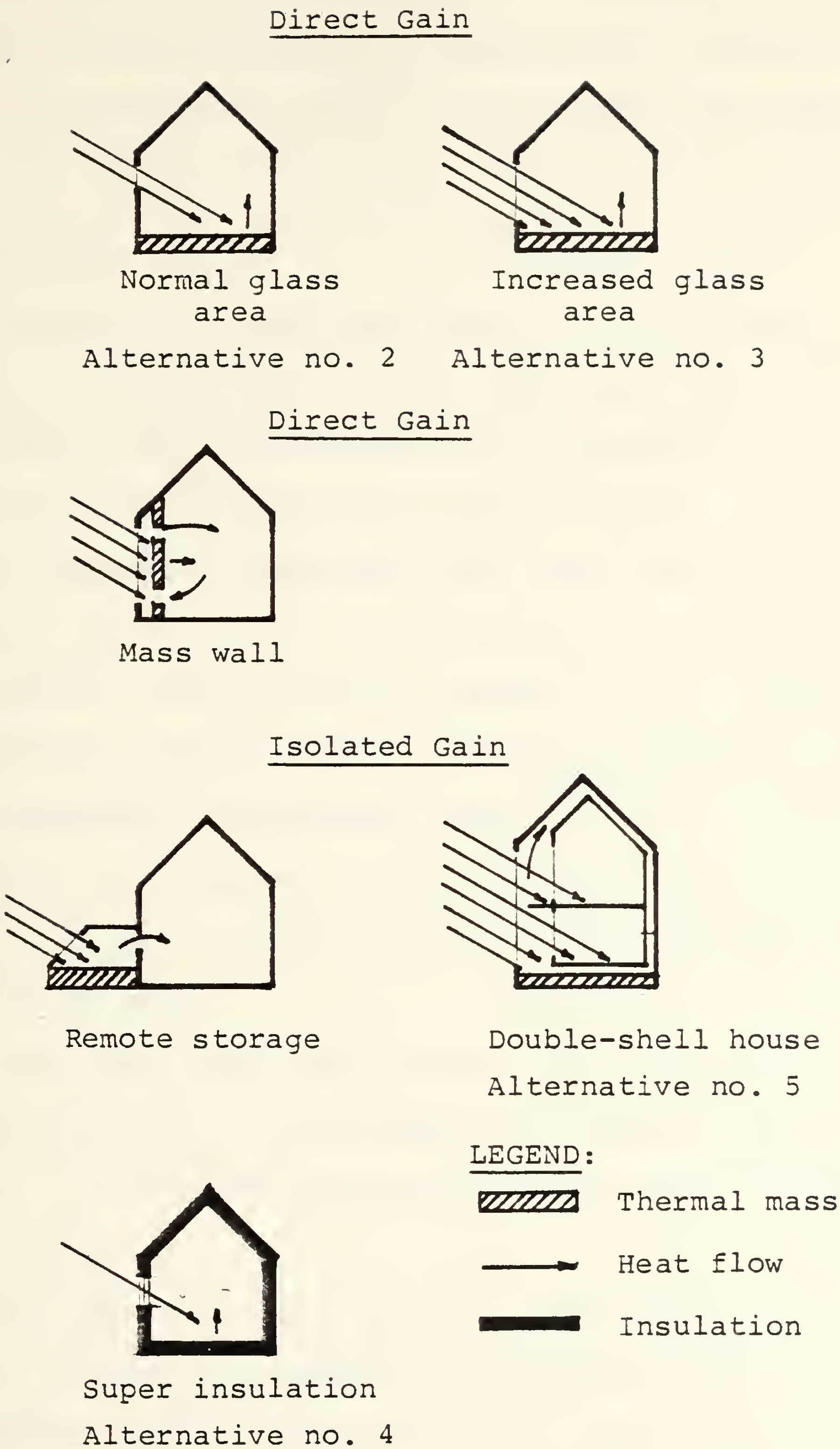


FIGURE 4-4 Examples of passive space-heating design alternatives

coefficient of heat transmission of the walls, floors and ceilings; (3) the difference in temperature (ΔT) between the outside air temperature and the inside design air temperature; (4) the wind velocity; and (5) the amount of air infiltration.

F. COST MODEL

The intent of the basic cost model that was used in the analysis was to determine the long range cost savings of the various passive solar space-heating alternatives as opposed to the costs experienced without solar heating. The factors that were included in the basic cost model were: (1) the cost per square foot of each of the alternatives; (2) the design and development costs, normally assumed to be 6 percent of the construction costs, coupled with the construction, supervision, inspection and overhead costs (S.I.O.H.) which normally averages 3.5 percent of the overall construction costs, giving a total R&D percentage figure of 9.5 percent, and (3) life cycle costs.

The life cycle costs were broken down into capital investment required, and operating and support costs, which included a 1-1/2 percent maintenance cost over a 25-year period of time.

For the purpose of this analysis, life cycle costs were defined as the sum of; operating and support costs, and capital investment costs. In computing the life cycle costs, the present values of fuel and maintenance costs were added

to the total initial investment costs for each alternative. The following formulas were used to determine life cycle costs:

$$\text{FUEL: } \begin{pmatrix}\text{Annual usage} \\ \text{in } 10^6 \text{ BTU's}\end{pmatrix}\begin{pmatrix}\text{Cost per} \\ 10^6 \text{ Btu's}\end{pmatrix}\begin{pmatrix}\text{Fuel} \\ \text{Escalation} \\ \text{Rate}\end{pmatrix}\begin{pmatrix}\text{D.O.D.} \\ \text{Discount} \\ \text{Rate}\end{pmatrix}$$

$$\text{MAINTENANCE: } \begin{pmatrix}\text{Annual} \\ \text{Maint.} \\ \text{Costs}\end{pmatrix}\begin{pmatrix}\text{Annual} \\ \text{Inflation} \\ \text{Rate}\end{pmatrix}\begin{pmatrix}\text{D.O.D.} \\ \text{Discount} \\ \text{Rate}\end{pmatrix}$$

$$\text{FIXED COSTS: } \begin{pmatrix}\text{Initial} \\ \text{Investment} \\ \text{Costs}\end{pmatrix} + (\text{R\&D})$$

Annual Life Cycle Costs:

$$\overbrace{\text{Fuel Costs} + \text{Maint. Costs}}^{\text{Operating and Support Costs}} + \overbrace{\text{Fixed Costs}}^{\text{Capital Investment Required}}$$

The factors indicated above were then calculated for each of the alternatives in each of the climate zones, to determine the break-even points for each of the alternatives. The life cycle cost graphs include a fuel inflation rate of 14 percent and assume the present Department of Defense discount rate of 10 percent. The graphs do not include any cost reductions from "tax rebates or incentives" that normally would be included in private sector analysis, as these were considered inappropriate to federal construction.

For the life cycle fuel cost graphs, the basic cost model was revised to include only the fuel portion of the operating costs, reflecting the total number of units within a climate zone. This was done for several reasons; first, the original purpose of the analysis was to indicate the amount of heat possible from various passive solar space-heating alternatives, not to determine the total cost of a complete heating system for the design house in each of the climate zones. Second, the R&D costs, investment costs and the maintenance costs were fixed costs as they did not vary from one climate zone to another, therefore they were not included.

G. EVALUATION

Table 4-2 shows the calculation summary of heat loss and heat gain computations as well as the percentages of the total space heat available, using passive solar alternatives.

Figures 4-5 through 4-9 graphically show the total life cycle costs and break-even points in years, for each of the alternatives presented, in each of the five climate zones within the continental United States.

Figures 4-10 through 4-14 graphically show the summary life cycle fuel cost comparisons for a single unit during the month of January in each of the five climate zones.

Figures 4-15 through 4-18 graphically show the heating potential amounts of passive solar space heating available for the month of January for each of the five climate zones,

TABLE 4-2 CALCULATION SUMMARY OF HEAT LOSS AND HEAT GAIN
Computations by Climate Zone in Btu's/day

Alternative	Total heat loss	Total heat loss	Auxillary space heating required	Percentage of total heat available from the sun
Climate zone no. 1				
1	231,534	0	231,534	0
2	231,534	139,400	117,866	60.2
3	187.488	225,000	(37,512)	120
4	71,680	139,400	(67,720)	194
5	93,408	299,200	(205,792)	320
Climate zone no. 2				
1	429,992	0	429,992	0
2	429,992	138,416	291,576	32.2
3	348,192	253,200	94,992	72.7
4	133,120	138,416	(5,296)	104
5	173,472	297,088	(123,616)	171
Climate zone no. 3				
1	595,373	0	595,373	0
2	595,373	134,316	461,057	22.6
3	482,112	245,700	236,412	51
4	184,320	134,316	50,004	72.9
5	240,192	288,288	(40,096)	120
Climate zone no. 4				
1	678,064	0	678,064	0
2	678,064	126,608	551,456	18.7
3	549,072	231,600	317,472	42.2
4	209,920	126,608	83,312	60.3
5	273,552	271,744	1,808	99.4
Climate zone no. 5				
1	909,598	0	909,598	0
2	909,598	114,308	795,290	12.6
3	736,560	209,100	527,460	28.4
4	281,600	114,308	167,292	40.6
5	367,752	245,344	122,408	66.7

TABLE 4-3 LIFE CYCLE COSTS

	Non-recurring costs			Recurring costs	
Alternative	Cost per SF	R&D 9.5%	Initial Investment Costs	Fuel	Maintenance 1.5%
1	$40	$5,320	$56,000		$840
2	$40	$5,320	$56,000		$840
3	$43	$5,719	$60,200	$3.29 per MBtu	$903
4	$47	$6,251	$63,800		$987
5	$45	$5,985	$63,000		$945

Note: Costs per square foot of construction were derived from National construction averages and have been modified to reflect the relative amounts of building materials required for each of the alternatives.

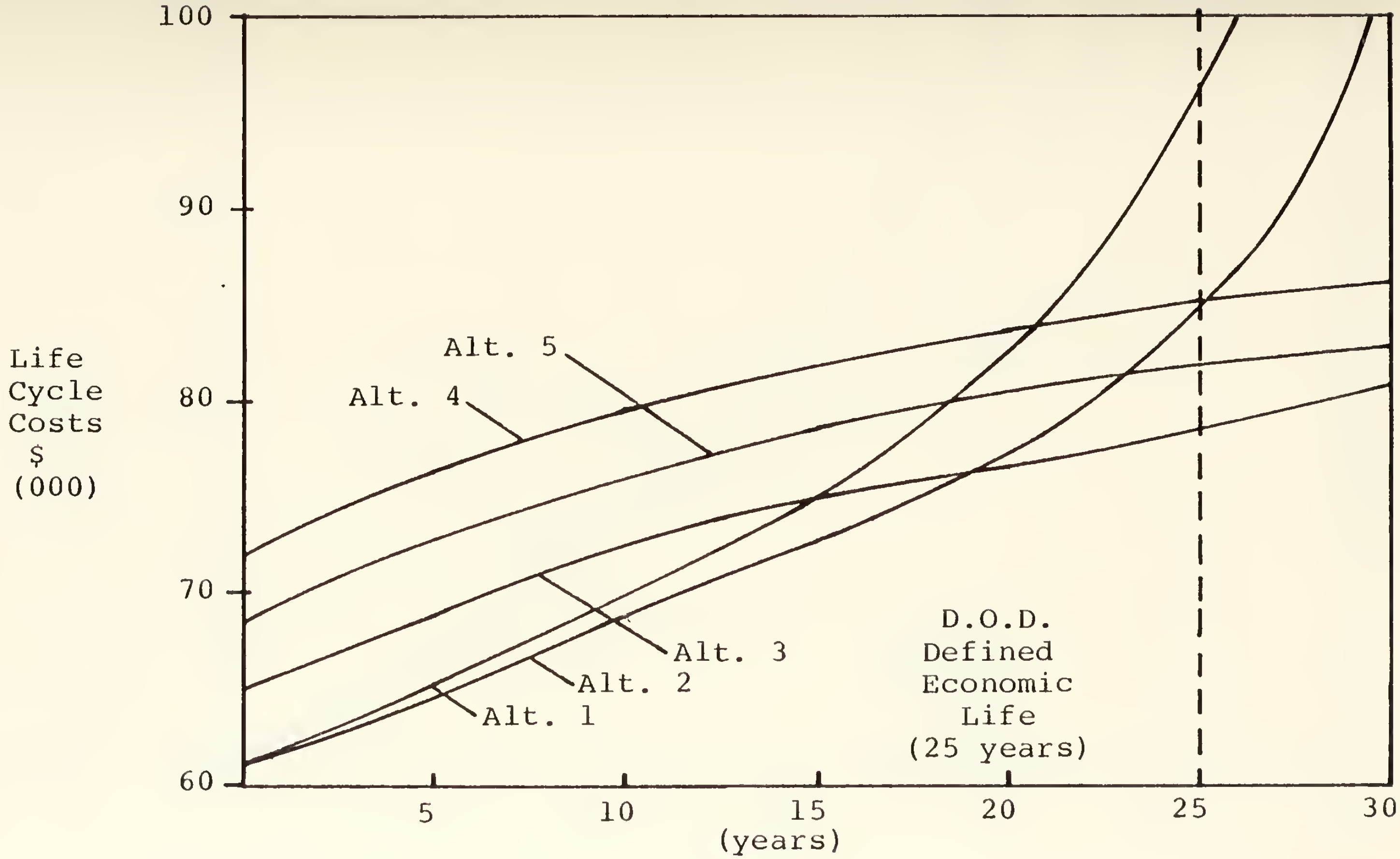


FIGURE 4-5 Life cycle cost graph for climate zone no. 1

Note: Figures 4-5 through 4-9 show the the comparisons of life cycle costs for each of the alternatives in each of the five climate zones. The figures were obtained by summing the present values of annual fuel costs, maintenance costs and fixed costs.

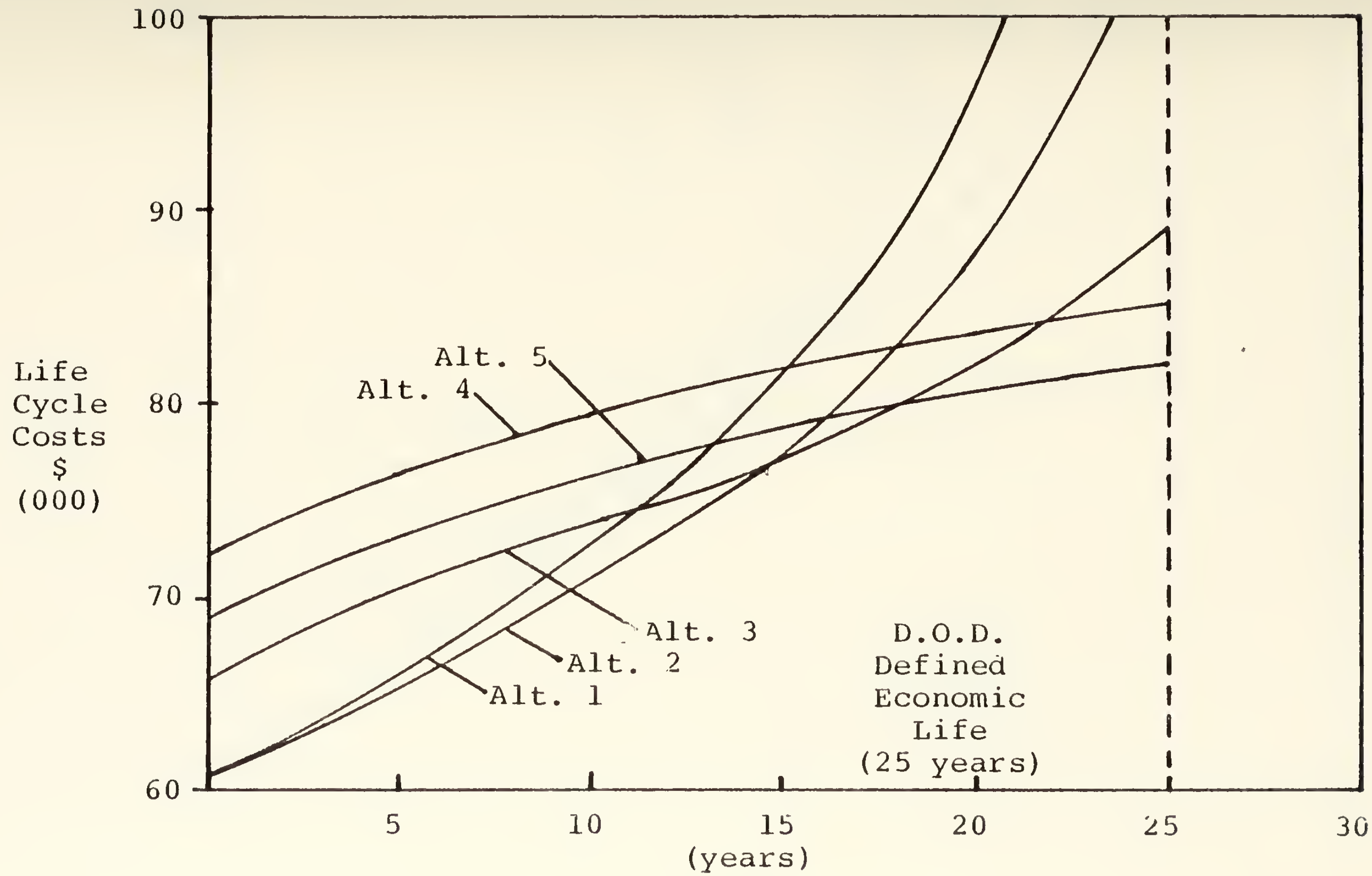


FIGURE 4-6 Life cycle cost graph for climate zone no. 2

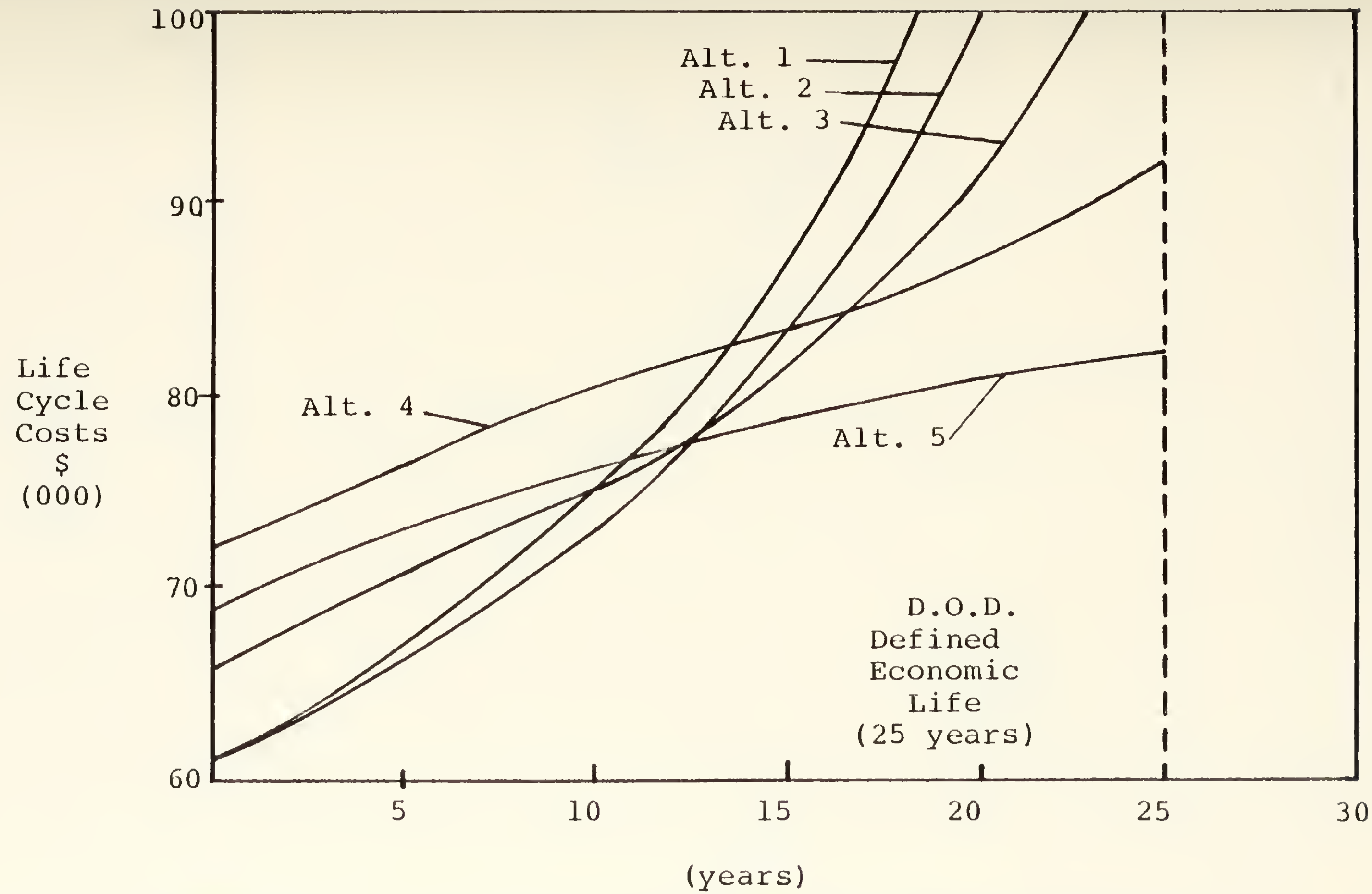


FIGURE 4-7 Life cycle cost graph for climate zone no. 3

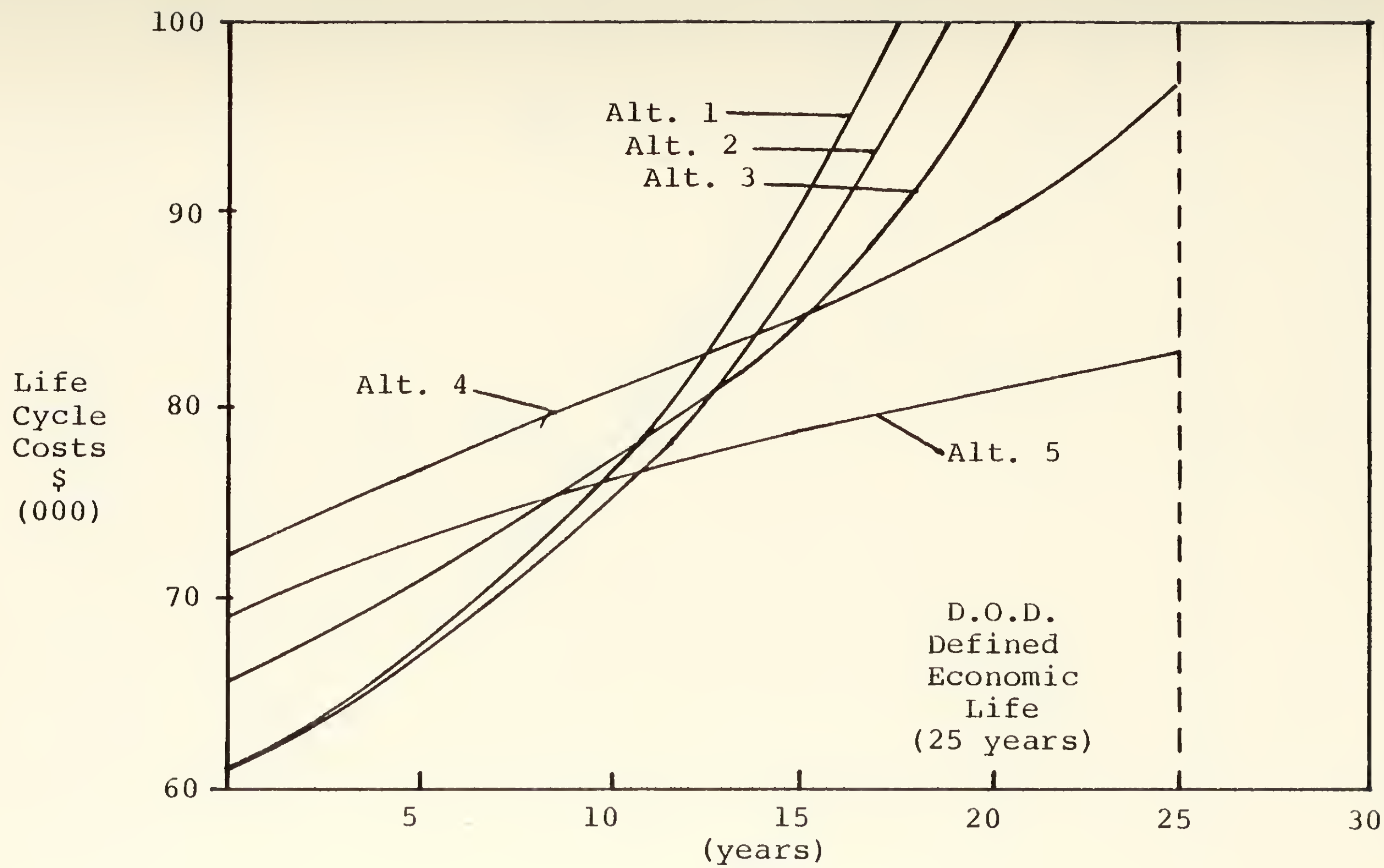


FIGURE 4-8 Life cycle cost graph for climate zone no. 4

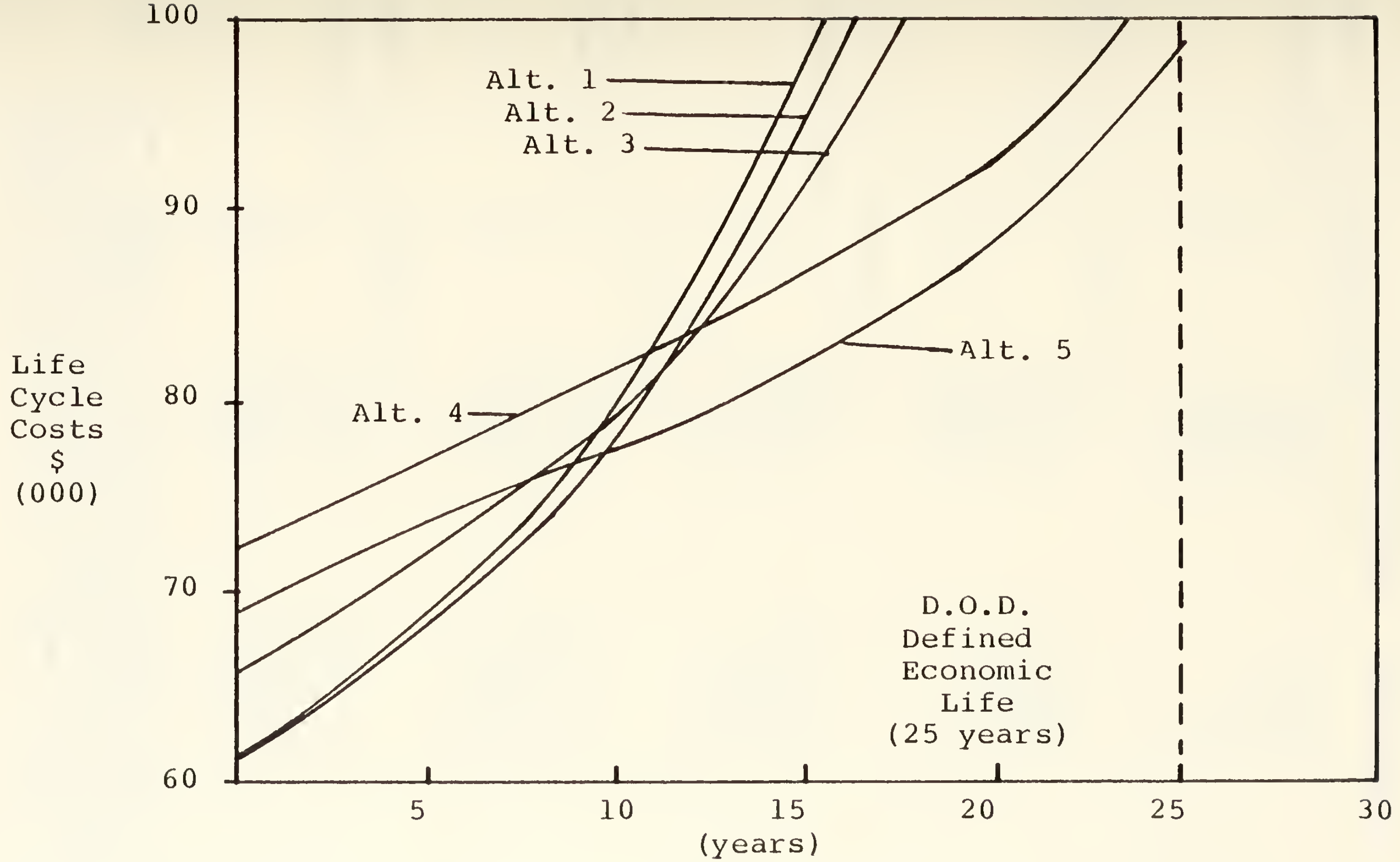


FIGURE 4-9 Life cycle cost graph for climate zone no. 5

TABLE 4-4 SUMMARY OF INDIVIDUAL UNIT LIFE CYCLE FUEL COST COMPARISONS FOR THE MONTH OF JANUARY - IN DOLLARS

		Without Solar	With Solar	Solar Savings
Zone no. 1 (Figure 4-9)				
Alternative	.1	5,950	5,950	0
	.2	5,950	3,029	2,921
	.3	4,818	0	4,818
	.4	1,842	0	1,842
	.5	2,400	0	2,400
Zone no. 2 (Figure 4-10)				
Alternative	.1	11,050	11,050	0
	.2	11,050	7,493	3,557
	.3	8,948	2,441	6,507
	.4	3,421	0	3,421
	.5	4,458	0	4,458
Zone no. 3 (Figure 4-11)				
Alternative	.1	15,301	15,301	0
	.2	15,301	11,849	3,451
	.3	12,390	6,075	6,314
	.4	4,737	1,285	3,451
	.5	6,172	0	6,172
Zone no. 4 (Figure 4-12)				
Alternative	.1	17,426	17,426	0
	.2	17,426	14,172	3,253
	.3	14,111	8,159	5,952
	.4	5,394	2,141	3,352
	.5	7,030	46	6,983
Zone no. 5 (Figure 4-13)				
Alternative	.1	23,376	23,376	0
	.2	23,376	20,438	2,937
	.3	18,929	13,555	5,373
	.4	7,237	4,299	2,937
	.5	9.451	3,145	6,305

Note: The figures in table 4-4 represent the present values (in dollars) of the 25-year fuel costs for each of the alternatives with and without solar space-heating techniques. The figures are based on heat loss/heat gain computations.

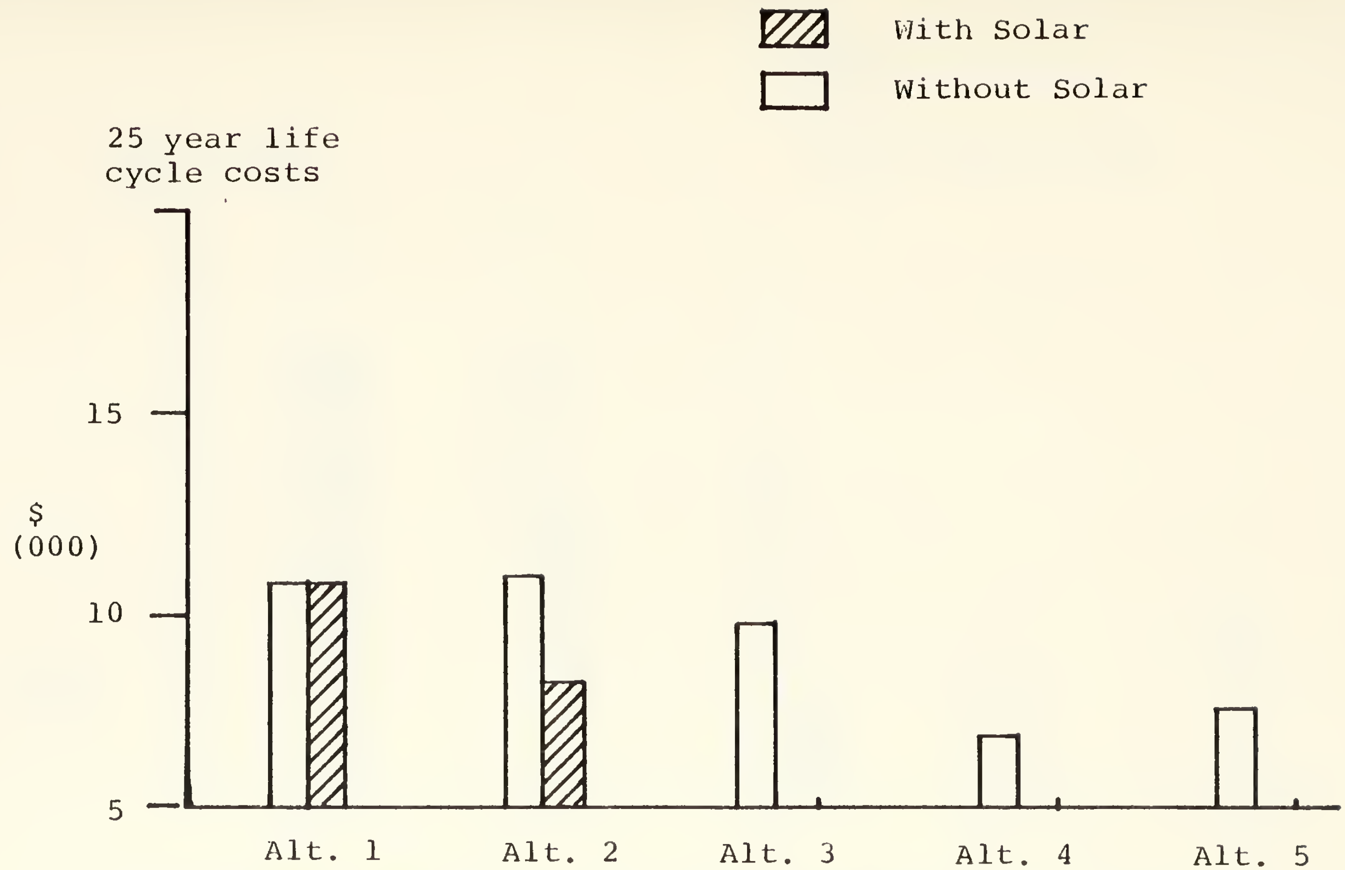


FIGURE 4-10 Summary of individual unit life cycle fuel cost comparisons, climate zone no. 1

Note: Because alternative no. 1 receives only a negligible amount of solar energy, the 25-year life cycle fuel costs, with and without solar, are the same.

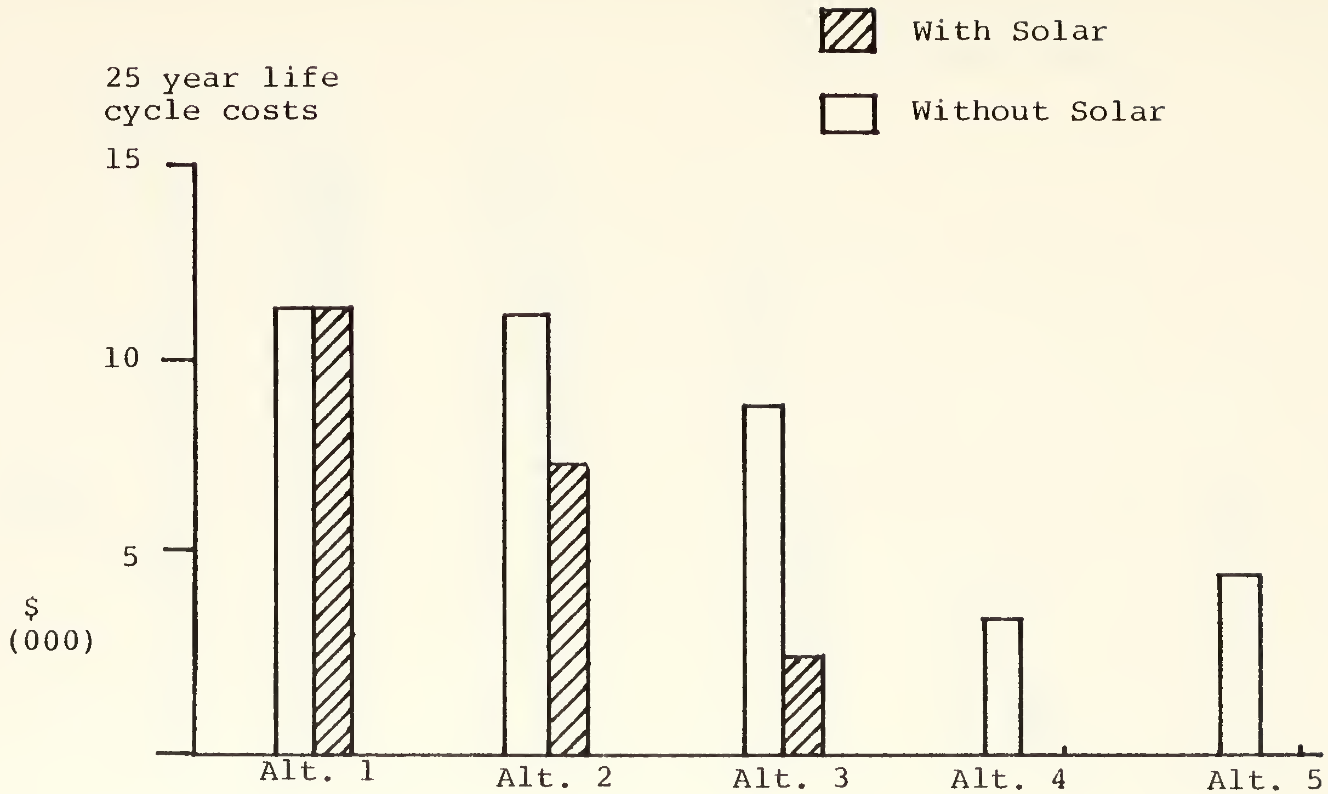


FIGURE 4-11   Summary of individual unit life cycle fuel cost comparisons, climate zone no. 2

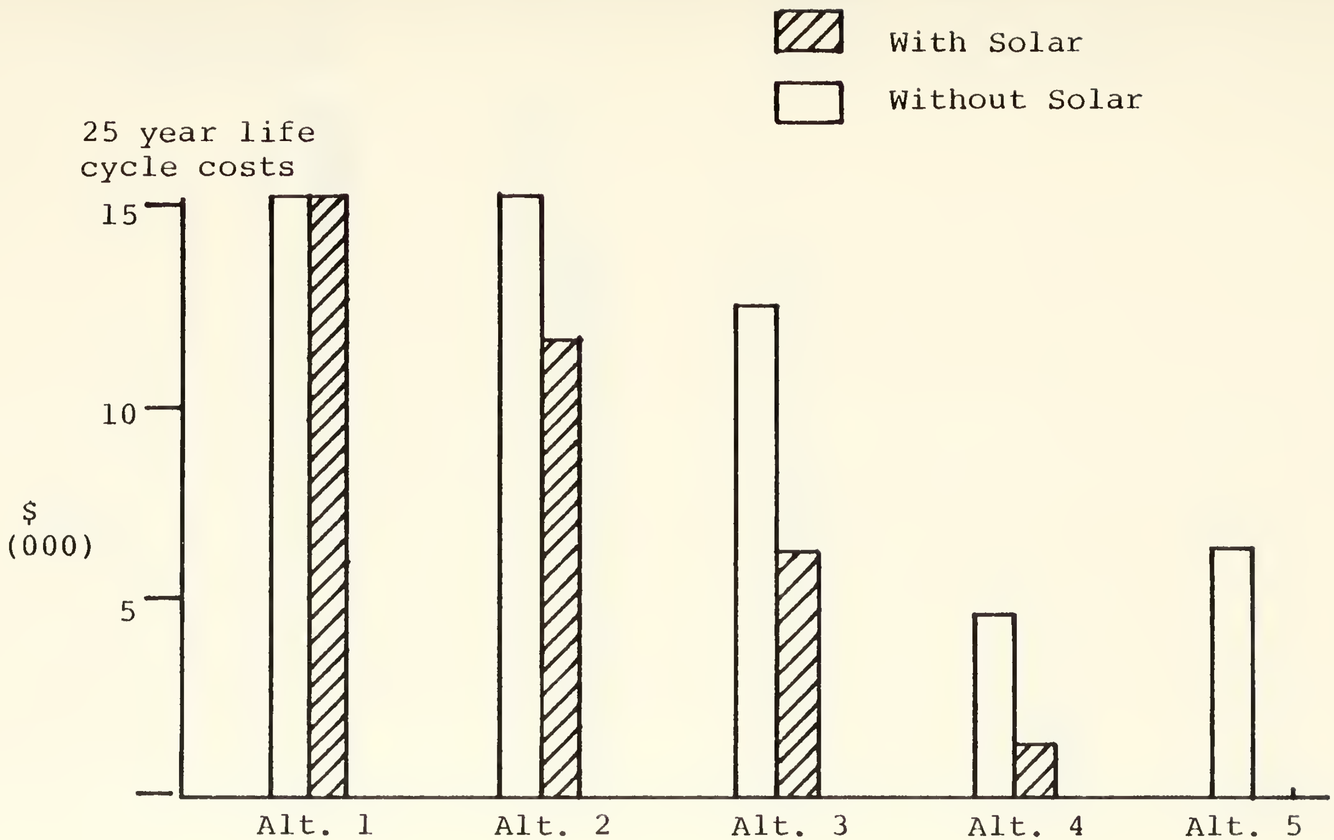


FIGURE 4-12 Summary of individual unit life cycle fuel cost comparisons, climate zone no. 3

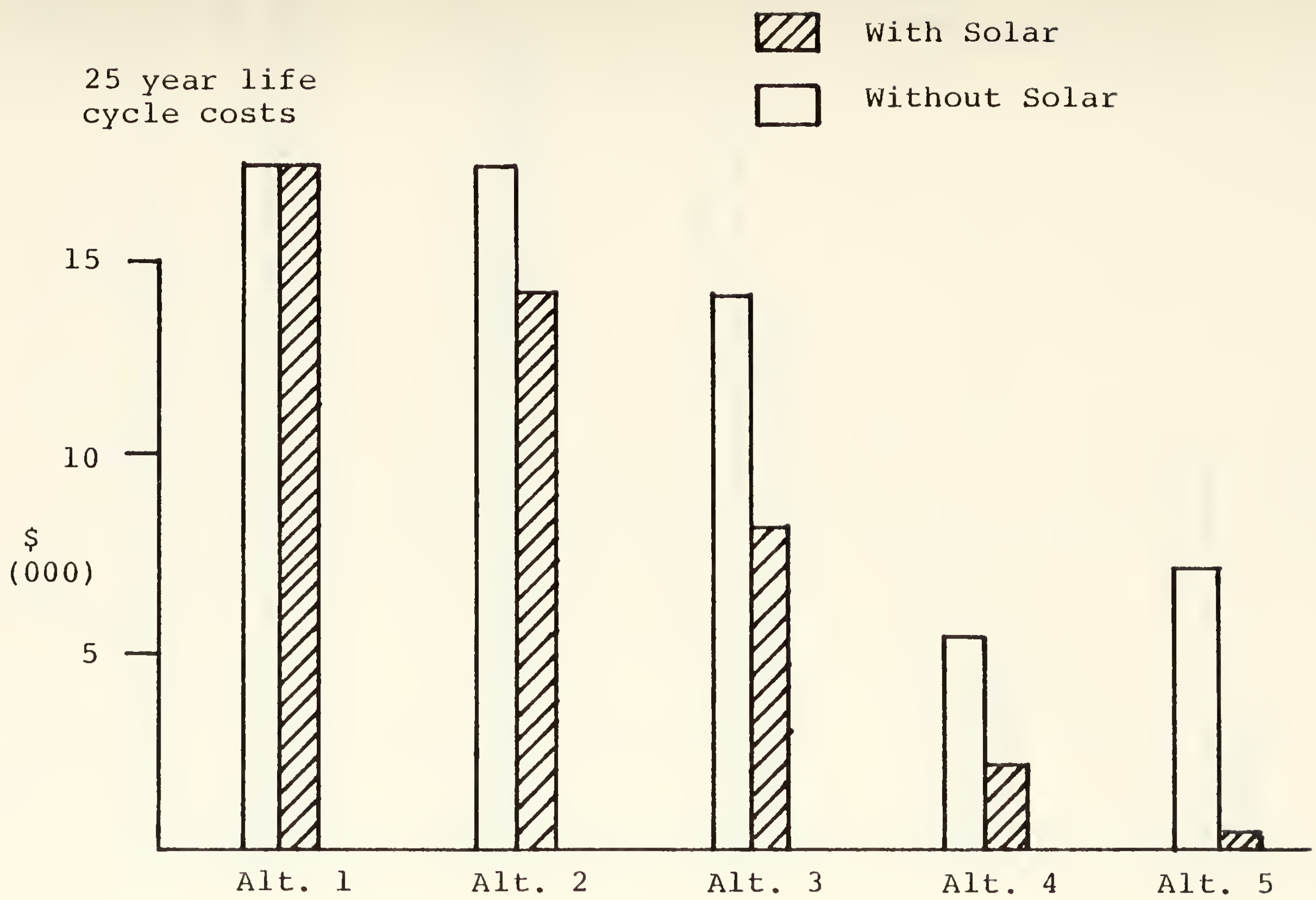


FIGURE 4-13 Summary of individual unit life cycle fuel cost comparisons, climate zone no. 4

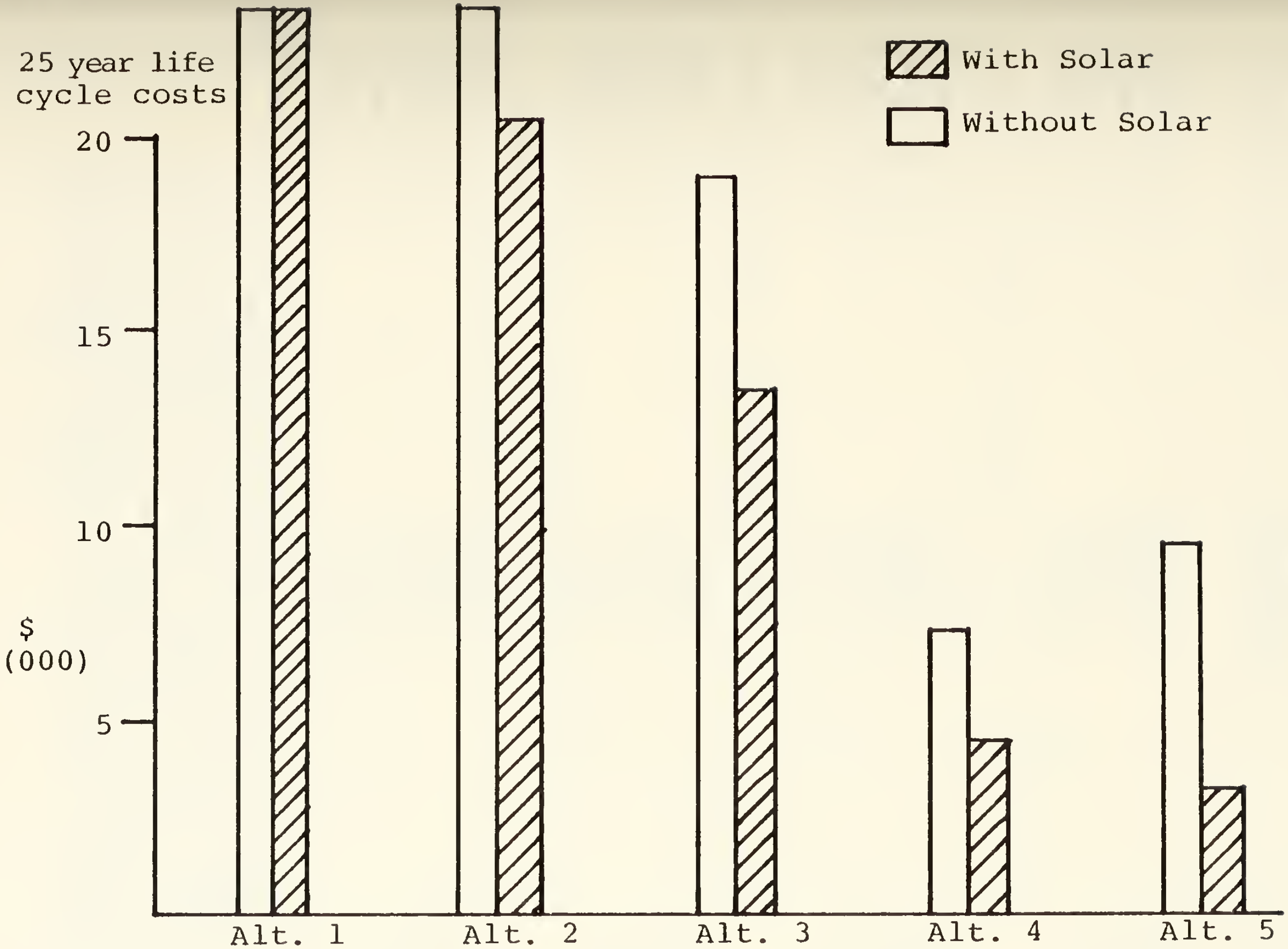


FIGURE 4-14 Summary of individual unit life cycle fuel cost comparisons, climate zone no. 5

TABLE 4-5 SUMMARY OF TOTAL SPACE-HEATING REQUIREMENTS FOR THE MONTH OF JANUARY IN BARRELS OF OIL EQUIVALENT

Alternative no. 1 & Alternative no. 2 (Figure 4-15)	Conventional heat required	Available solar
Zone no. 1	140,632	84,660
Zone no. 2	161,612	52,039
Zone no. 3	155,685	35,185
Zone no. 4	89,226	16,685
Zone no. 5	24,495	3,086
Alternative no. 3 (Figure 4-16)		
Zone no. 1	113,834	136,600
Zone no. 2	130,880	95,150
Zone no. 3	126,075	64,298
Zone no. 4	72,255	30,492
Zone no. 5	19,837	5,634
Alternative no. 4 (Figure 4-17)		
Zone no. 1	43,510	84,409
Zone no. 2	50,040	52,041
Zone no. 3	48,200	35,138
Zone no. 4	27,625	16,658
Zone no. 5	7,583	3,079
Alternative no. 5 (Figure 4-18)		
Zone no. 1	56,698	181,433
Zone no. 2	62,086	106,167
Zone no. 3	62,810	75,372
Zone no. 4	36,000	35,784
Zone no. 5	9,903	6,605

Note: The figures presented in Table 4-5 indicate the calculated amounts of conventional heat required (in barrels of oil equivalent) for the total number of family housing units in each climate zone. These figures are compared to the potential amounts of passive space-heating available. These figures correspond to the percentages of total space heat available from the sun - Table 4.2.

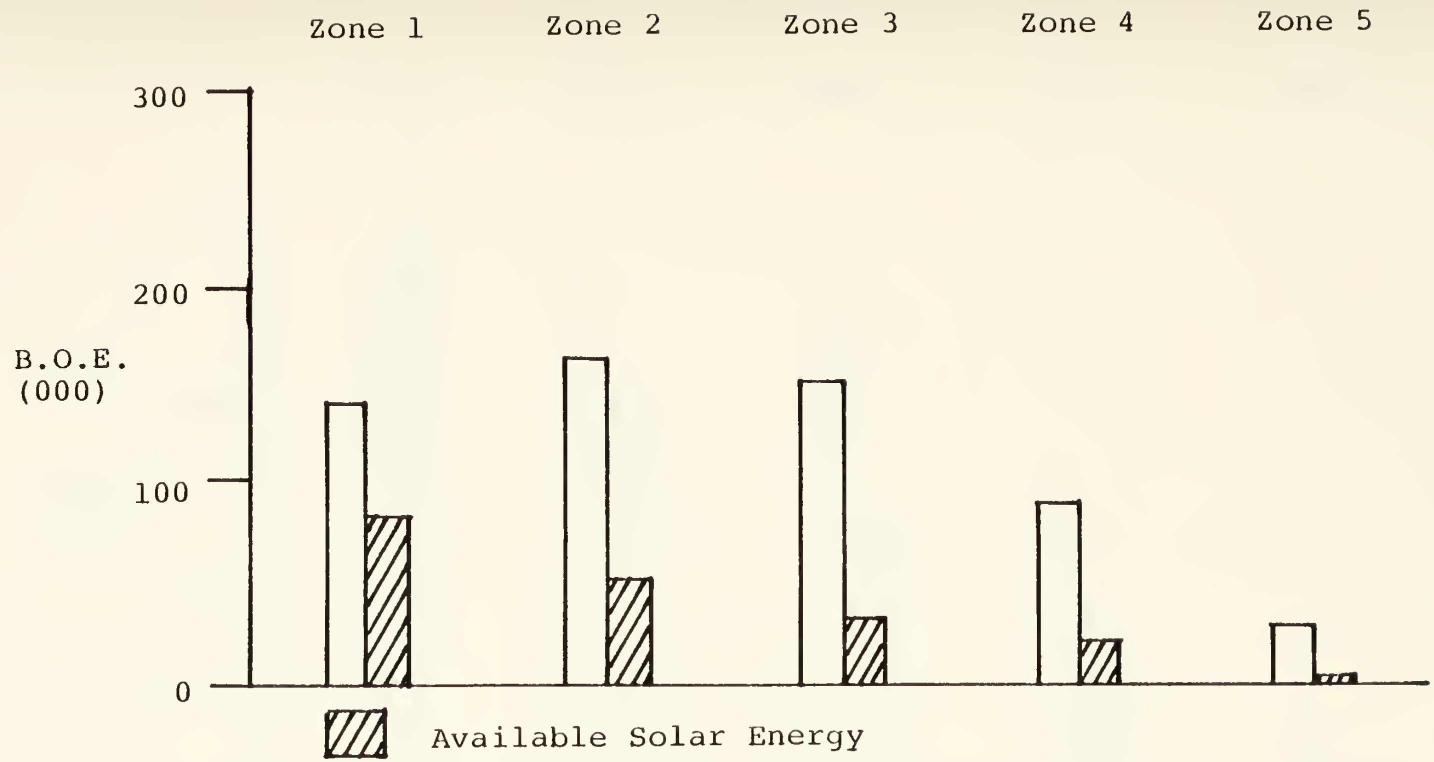


FIGURE 4-15 Potential amounts of passive space-heating available Alternative no. 2 (in barrels of oil equivalent)

Note: In climate zone no. 1, 60.2 percent of the total space heat required could be supplied by alternative no. 2.

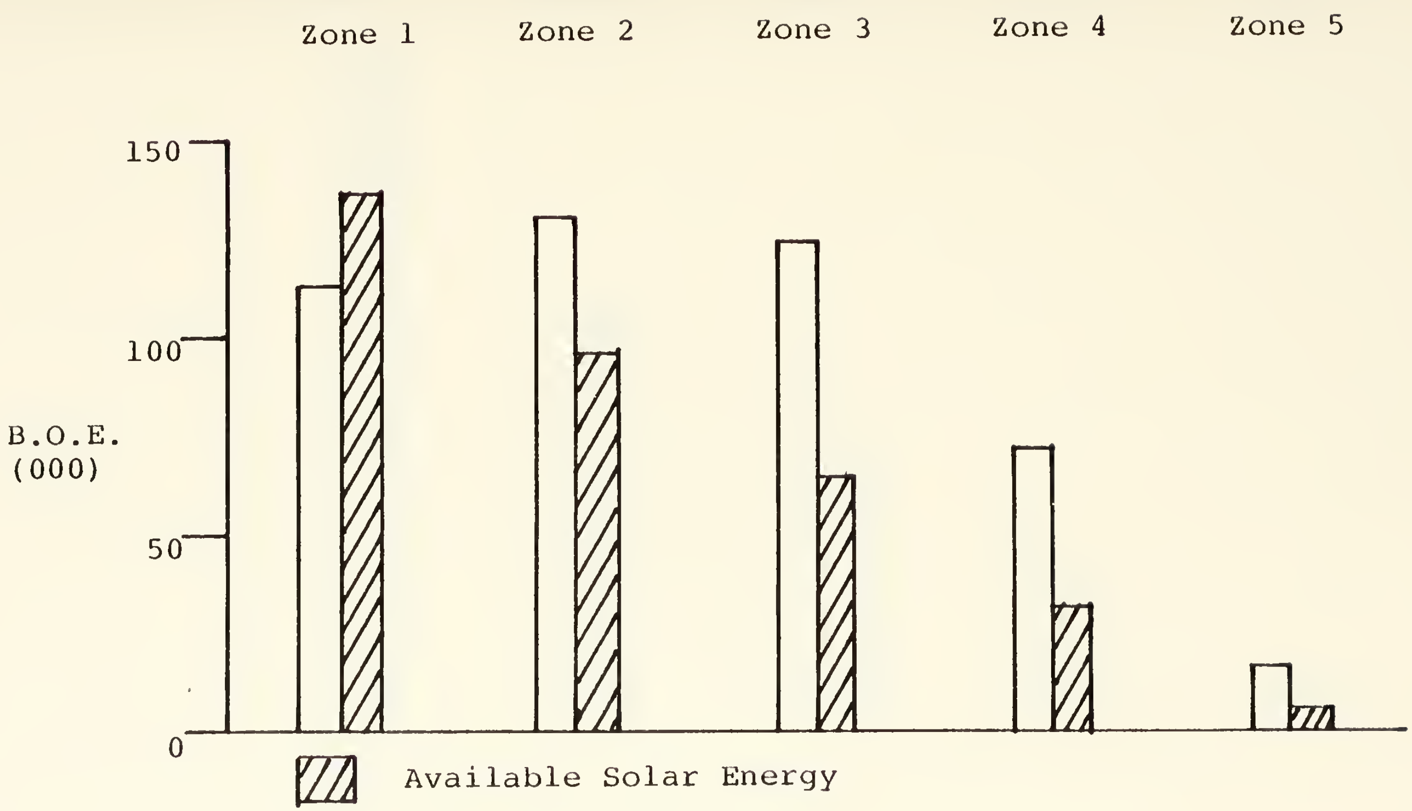


FIGURE 4-16 Potential amounts of passive space heating available Alternative no. 3 (in barrels of oil equivalent)

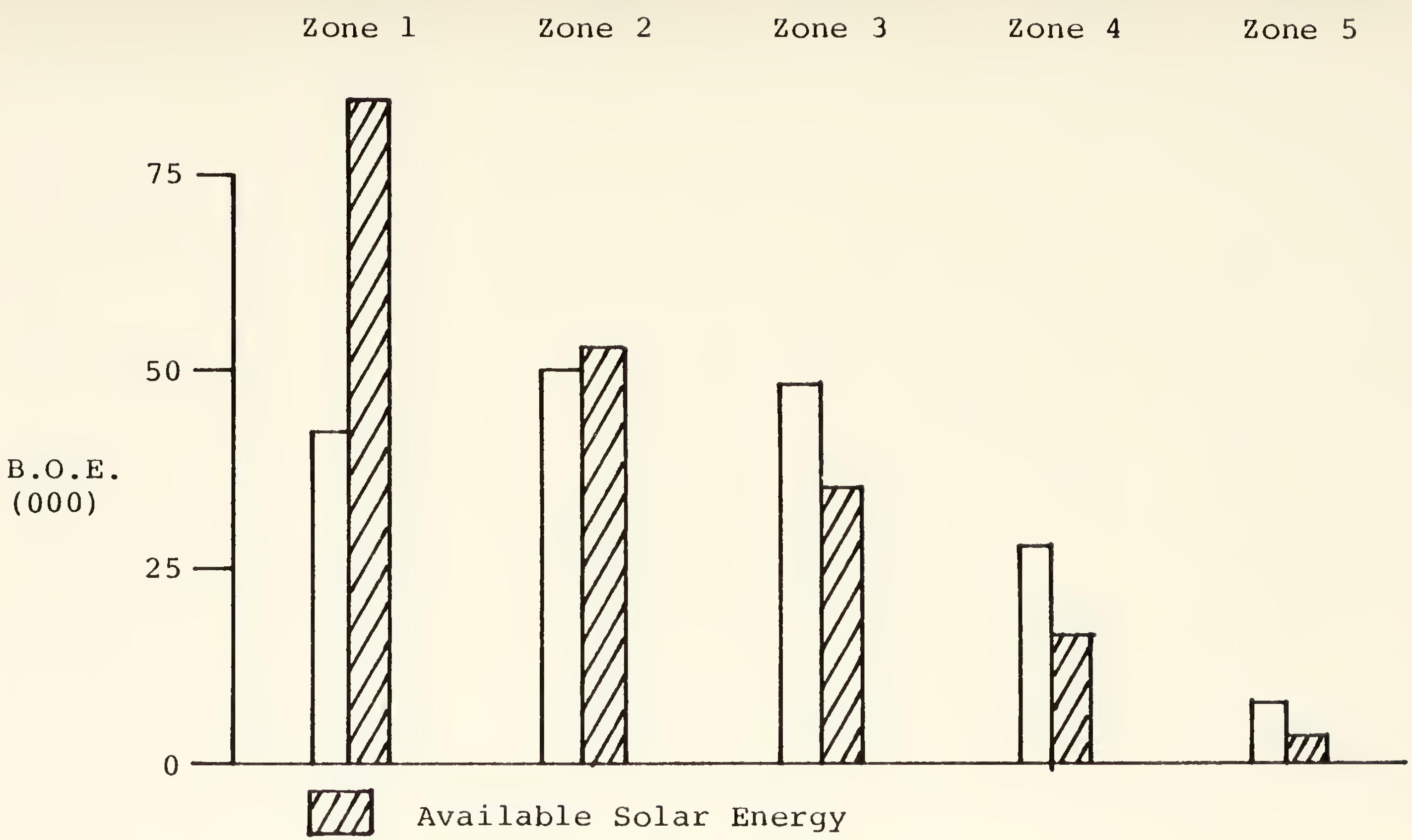


FIGURE 4-17 Potential amounts of passive space heating available Alternative no. 4 (in barrels of oil equivalent)

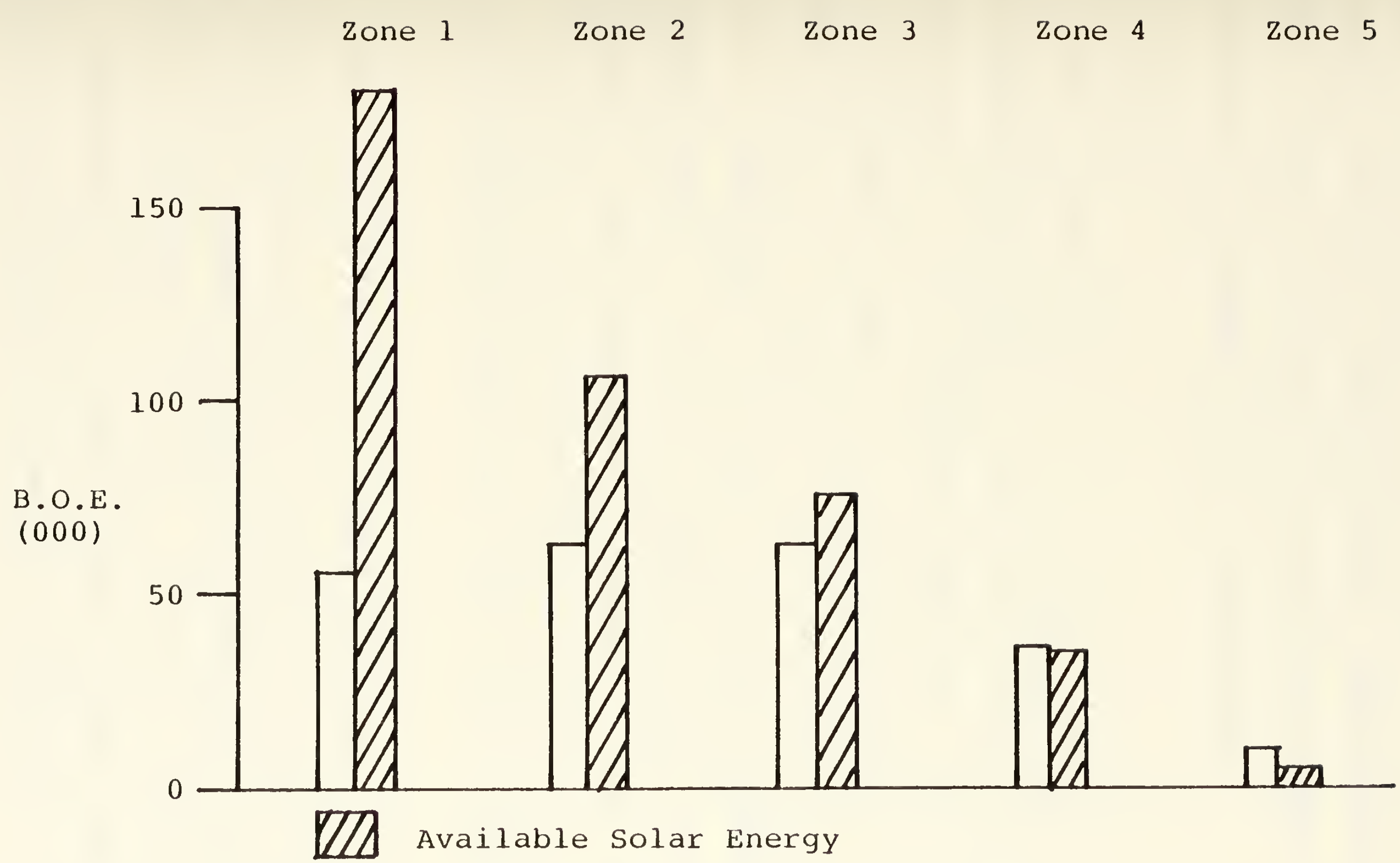


FIGURE 4-18 Potential amounts of passive space heating available Alternative no. 5 (in barrels of oil equivalent)

by alternative, in barrels of oil equivalent. These graphs reflect the amounts of space heat required for the total number of family housing units located within a particular climate zone at an interior design temperature of 65°F. These graphs also reflect the potential amounts of energy available from passive solar alternatives.

H. RESULTS

The analysis was run at an interior temperature of 65°F, the temperature used as a basis for determining solar degree days [Ref. 2]. The analysis showed that for alternative no. 2, orienting the house to a southern exposure, the design house was able to acquire as much as 60.2 percent of the Btu's it required to maintain its design temperature in climate zone no. 1 and 12.6 percent in zone no. 5. Further, alternative no. 2 realized an average 25-year life cycle fuel cost savings, for all five climate zones of $3224.27 with a high of $3557.29 in zone no. 2 and a low of $2921.27 in zone no. 1.

For alternative no. 3, which increased the amount of southern exposed glass by 50 percent, it was found that as much as 120 percent of the BTU's required to heat the house could be supplied in zone no. 1 and 28.4 percent in zone no. 5. Alternative no. 3 also had the highest average life cycle fuel cost savings with an amount of $5793.23.

When the insulation values of the design house were increased, as in alternative no. 4, the analysis showed that the total heat loss of the unit was substantially lowered. But because the square footage of southern exposed glass was kept the same as in alternative no. 2, the heat gain was minimal. Still, the analysis showed that 194 percent of the energy required to heat the house could be supplied in zone no. 1 and 40.6 percent in zone no. 5. In addition, because the heat gain was kept at a minimum, the life cycle fuel cost savings were the lowest at an average of $2981.36.

Alternative no. 5 showed the greatest amount of excess Btu's absorbed, over 200,000 or 320 percent in zone no. 1 and 59.2 percent in zone no. 5. This double wall technique shows great promise, not only for its ability to absorb large quantities of excess Btu's but because of its average life cycle fuel cost savings of $5264.18.

The life cycle costs that were calculated, indicated that alternative no. 1 - do nothing, was the most expensive in all five climate zones, exceeding $100,000 dollars in climate zone no. 5 at the fifteen-year point. By comparison, alternative no. 5 - the double-shell house, was the least expensive in four out of five climate zones. The life cycle cost graphs, Figures 4-5 through 4-9, indicated that the magnitude of the 25-year life cycle costs were directly related to the passive solar space-heating potential of the

design alternative. The greater the amount of absorbed solar energy, the lower the life cycle costs. The graphs also indicate that the break-even points of passive solar design alternatives average in the range of 10 to 15 years.

I. SENSITIVITY ANALYSIS

In conducting the analysis a number of factors were kept constant for ease of calculations. The first of these factors was the orientation of the design house. All of the alternatives, with the exception of alternative no. 1, faced due south to maximize heat gain. It was noted that by rotating the house a number of degrees away from due south, a substantial amount of solar heat gain would be lost. Closely related to the orientation angle, is the altitude angle of the sun. In this analysis the representative cities chosen all used altitude angles corresponding to the climate zone in which they were located. It was noted, however, that an increase or decrease in the latitude would have a corresponding decrease or increase in the altitude angle, thereby varying the amount of available solar heat.

The second factor that was kept constant was the tilt angle of the glass, for the analysis all glass was assumed to be vertical. Appendix F is provided to show how the tilt angle of the surface would affect the amount of solar energy intercepted. By superimposing a specific surface angle from Appendix F on the solar heat gain charts, Appendix D, it is

possible to determine the total amount of solar energy available from a surface at any angle, time or date for the solar heat gain charts provided. For those individuals who require a more accurate method, sun location formulas are provided in Appendix E.

Another factor that was kept constant throughout the analysis was wind velocity. Wind velocity is normally considered to be 15 mph for all conditions and any velocity below this figure is not considered. However, as the wind velocity exceeds 15 mph, the total calculated heat loss must be increased. Wind velocity factors are provided in Appendix G.

Because the analysis was conducted for a finite period of time, weather was not included as one of the varying factors, other than to determine the maximum and minimum outside air temperatures. If the analysis were to be substantially expanded, the probability of adverse weather would become an important factor. However, the month of January was chosen for this analysis as it had the most severe heating requirements in all of the climate zones indicated.

All of the above factors had their greatest effect or potential effect, when included in the effectiveness model. However, as indicated earlier, the factor that affected the cost model the most was the rising price of fossil fuels. Appendix I is provided to show various projected gas fuel prices as they relate to life cycle costs.

V. THE ADVANTAGES AND DISADVANTAGES OF SOLAR ENERGY TO THE DEPARTMENT OF DEFENSE

As a result of the 1973 oil embargo and the subsequent increases in the cost of petroleum, solar energy has emerged as one of the proposals to help reduce the energy consumption of the Department of Defense. Solar energy has specific advantages and disadvantages as an alternative energy source for the Department of Defense. Pertinent advantages are presented and briefly discussed.

A. ADVANTAGES

1. Continuously renewable source

Solar energy (radiation), due to its origin, is virtually inexhaustible and with almost unlimited availability. "The energy output of the sun requires the burning or conversion of mass into energy at a rate of 4.2 million tons per second. Assuming that the sun has been in the hydrogen burning stage for 6 billion years, this seems at first glance like a great loss. A closer look shows the total mass of the sun to be approximately 2.2×10^{27} tons, so that the sun loses only 2.0×10^{-20} percent of its mass each second. At this rate, the sun can be expected to continue radiating energy for billions of years to come" [Ref. 2].

Because of its unlimited availability, it requires no depletion allowance to encourage exploration. In addition, it cannot be controlled and embargoed by a few oil producing nations.

2. Relatively low cost

Solar energy is free, except for the initial capital cost of intercepting it and converting it to a usable form. However, this initial capital investment cost is one of the primary reasons why solar energy is not cost effective on a broad scale with conventional heating systems. Construction costs are often quite substantial. However, a major cost advantage is that once a solar energy system is constructed, the sun's energy from that point on is "free" and has virtually no inflationary effect, except perhaps, those costs associated with maintenance and repair. "Although cheap and convenient fossil fuels have made solar heating unattractive to much of the world, there are hidden costs associated with the use of conventional fuels such as the costs to future generations who will bear the consequences of our excessive use of natural resources, and environmental damage" [Ref. 18].

3. Cost effective source

Fossil fuels are extremely costly now and will continue to escalate in prices as finite supplies diminish. This means solar energy systems both active and passive are cost effective in many situations now. This trend should continue in the foreseeable future. Solar energy systems constructed or installed today have a life expectancy of approximately 20 to 25 years [Ref. 2]. The life cycle cost figures associated with these solar energy systems reflect substantial cost savings over conventional heating systems.

An additional advantage often overlooked is the maintenance and repair costs of the system. Maintenance and repair costs associated with solar energy systems are small compared to those of petroleum fired generating systems [Ref. 11].

4. State of the art technology

Solar energy has been used and developed by man for over 3000 years of recorded history [Ref. 13]. The technology the United States is using today is still in its infant stage of development. If this technology is allowed to continue at its present rate, it could lead to energy self-sufficiency for the United States by the middle of the 21st century. There is a need for improved technology in active heating and cooling applications, but the technological problems are relatively minor in nature and can be overcome. The technology for passive solar energy use for space heating is available today [Ref. 2].

5. Environmentally attractive

Solar energy is quiet, clean and non-polluting. It does not require large generating plants or central distribution systems. It does not require gigantic transportation networks or pipelines. It can be produced in small energy converters or collectors wherever the energy is to be used. Unlike oil, solar energy does not have the potential to blacken the beaches or rivers with spillage, or darken the skies or pollute the air we breath or the water we drink. Unlike coal, solar energy does not ravage the rural landscapes

with strip-mining or pollute urban atmospheres with sulfureous fumes. Unlike wood, solar energy cannot be fired by lightning strikes in drought-strickened forests or by carelessly tossed matches, causing the loss of thousands of acres of valuable timber and watershed [Ref. 19]. Unlike nuclear energy, solar energy does not have the potential of massive radiation accidents or core meltdowns, which could put millions of people in danger of radioactive contamination and possible death.

6. Energy self-sufficiency

Because of the diffuse and universal nature of solar energy, that is, it is available without regard to physical, political or human boundaries, its generation is not centralized or limited to specific locations. This fact will enable the Department of Defense to consider locations for future military installations, that would otherwise not be considered.

On a macro scale, solar energy will allow settlement of remote areas of the earth, and would promote development and modernization of those regions.

B. DISADVANTAGES

Unfortunately, solar energy cannot be considered the panacea for the Nation's energy problems. In fact, there are major disadvantages, or drawbacks, to the use of solar energy systems.

1. Technical drawbacks

One of the disadvantages associated with solar energy is that the systems are dependent upon the incidence of sunlight. Therefore, those locations at latitudes further from the equator, or those areas frequently obscured by clouds, will find solar systems less efficient and necessitate larger systems with their associated higher costs.

Another major disadvantage closely coupled with the incidence of sunlight, is the technical problems associated with heat storage. Solar systems use only a portion of the energy collected immediately, the rest must be stored for future use when demanded by the user. The cost of storage is often a considerable part of the investment required. However, research and development in the area of solar heat storage facilities and materials, the use of eutectic salts as an example, will eventually lead researchers to develop highly efficient solar heat storage techniques.

2. Economic drawbacks

The economic disadvantages of solar energy systems primarily stem from the high initial investment costs that are required, even though the operating costs and life cycle costs are lower than for conventional systems.

3. Miscellaneous drawbacks

There are countless disadvantages and drawbacks to solar energy that could be presented, but one author in the field of solar energy summed up its disadvantages;

"Solar energy has the drawback of being diffuse. Rather than being mined or drilled at a few scattered places, it falls thinly and fairly evenly across the globe. ... Government and industries accustomed to concentrated energy supplies are ill-equipped by reason of economic constraints or philosophical prejudices, to harness this gentle source of energy. These institutions are far more interested in forms of energy that lend themselves to centralization and control. Hence, the United States Government spends billions for nuclear power while solar energy is just a subject for study--a future possibility, maybe, but not for now" [Ref. 20].

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

According to a recent study by the California Energy Commission, by the year 1990, the United States can displace about 40 percent of the projected use of natural gas in residences, and about 10 percent of the electricity with solar energy systems that are known to be cost effective today. By the year 2000, the President's Council on Environmental Quality estimates that 25 percent of the energy in the United States could come from solar energy sources. That is equivalent to 10 to 12 million barrels of oil a day. Over the next 20 years, which is a relatively short period of time to make such a major change, the United States can go from essentially zero to 10 to 12 million barrels of oil displaced by solar. This figure is more than double the United States' current imports of about 6 million barrels a day.

Although solar energy is not the panacea that scientists depict it, solar energy still holds enormous potential for alleviating the United States' future dependence on expendable fossil fuels.

The Department of Defense can make a major contribution to the development of solar energy by beginning to incorporate proven passive space-heating techniques in family housing construction. The typical military installation is in essence a microcosm of the energy consuming public in that all

essentials of the residential, industrial, commercial and transportation sectors are represented. They therefore are in a position to act as proving grounds and provide prototypes for solar energy systems, in order that solar energy will gain the necessary visibility and large scale operational data required for National acceptance. Since the Department of Defense owns approximately 80 percent of the buildings controlled by the Federal Government, it is the greatest single potential government user of solar systems, and as such, provides the largest single market potential for passive solar space-heating systems [Ref. 6].

Chapter II discussed the impending energy problem facing the Department of Defense. It is concluded that if the world continues using energy at its present rate, that it will, in all probability, due to the finite quantity of the fossil fuel resources available, see the exhaustion of those resources early in the next century. The implications of the findings of the Workshop on Alternative Energy Strategies are already being experienced by the United States, cutoffs of imported oil and escalating fuel prices. In spite of the energy crisis, the Department of Defense must maintain its defense posture through continued training. To accomplish this, the Department of Defense must begin to develop methods of re-allocating fossil fuel resources from the support activities to the operational units. One method of re-allocating these resources

is through the use of passive solar space-heating techniques in family housing units throughout the continental United States.

Chapter III discussed the principles of passive design and presented brief definitions of heat transfer techniques within a passive solar design. Essential features and elements of passive design as well as the concepts of direct gain, indirect gain, and isolated gain were presented.

Chapter IV examined five solar space-heating alternatives and analyzed them for their passive solar potential in five climate zones within the continental United States. The analysis was conducted by means of a hypothetical single family unit reflecting the median characteristics of all family housing units located within the continental United States.

From the results that were obtained from the analysis, certain key conclusions can be drawn. As fuel costs continue to escalate at a rate faster than inflation due to their finite and non-renewable nature, there will be a corresponding dramatic increase in family housing utility costs. This increase in utility costs will allow passive solar space heating to reach break-even points, compared to conventional heating, at about the ten to fifteen year point. The analysis showed that for several of the alternatives, the amount of passive solar space heating available was in excess of the

amounts required to maintain the desired interior design temperature. The analysis further demonstrated that the use of passive solar systems significantly reduced space-heating costs in all climate zones. The dollar savings are large, amounting to hundreds of thousands of dollars over the economical life of the buildings. By averaging the percentages of passive solar space-heating potentials for each of the five design alternatives in each of the five climate zones, it can be estimated that 60 percent of the required space heating can be achieved by passive solar space-heating techniques. Figure 6-1 shows the projected utility costs for family housing units incorporating passive space-heating alternatives at a replacement rate of four percent per year (assuming constant construction costs).

Family housing units use approximately 3 percent of the total petroleum energy consumed by the Department of Defense. A 60 percent savings realized from passive solar space-heating techniques in these units would reduce the total annual energy and financial requirements to the Department of Defense by approximately 1.8 percent. In 1985, this figure would be approximately $104 million dollars.

The petroleum fuel that is saved by utilizing passive solar space-heating techniques in family housing units can be re-allocated to the operational units, thereby extending the operational life of the petroleum-powered weapons systems in

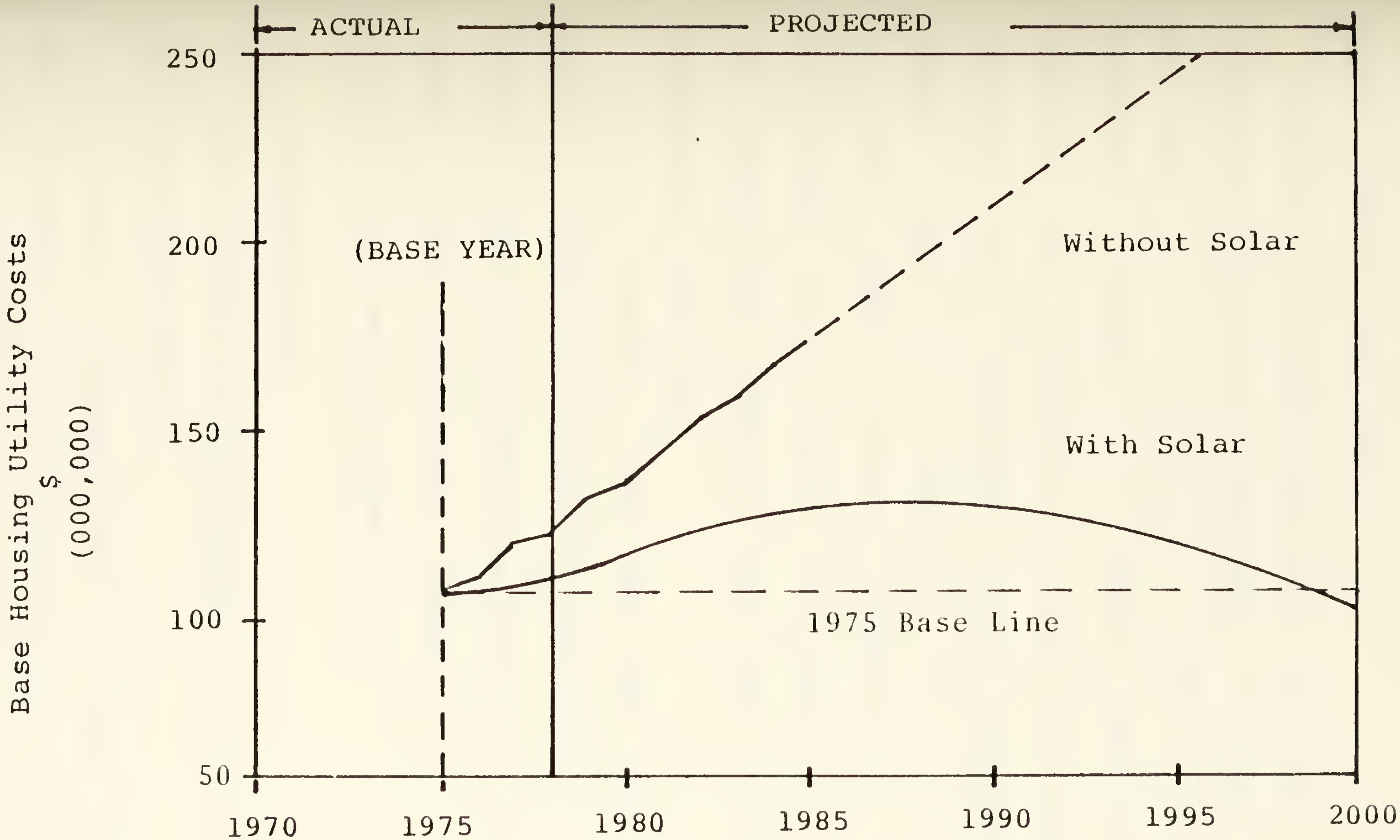


FIGURE 6-1 Projected utility costs for family housing units

Note: The term "with solar" means incorporating passive design techniques to family housing units at an arbitrary replacement rate of 4 percent per year. The total family housing utility costs will drop below the 1975 base figure by the year 2000. The term "without solar" indicates the projected family housing utility costs associated with not incorporating passive design techniques.

inventory. In 1978 the amount of petroleum products that could have been re-allocated was approximately 3 million barrels of oil equivalent.

Chapter V presented pertinent advantages and disadvantages of solar energy to the Department of Defense. Solar energy was shown to be a continuously renewable source that can be expected to continue for billions of years to come. It is a low cost source of energy whose long term cost effectiveness is greater than conventional sources performing similar functions. Finally, solar energy was shown environmentally attractive, quiet, clean and non-polluting. Unfortunately, solar energy is not without its drawbacks. High initial costs and technological problems in the area of thermal storage are still to be resolved.

It is concluded by the author that the long term advantages and benefits that will be realized by incorporating passive solar space-heating techniques in government family housing units, far outweigh the short term disadvantages and drawbacks that will be experienced.

B. RECOMMENDATIONS

Based on the results obtained in this study, the Department of Defense should:

1. Begin to develop plans to convert the approximate 263,000 family housing units within the continental United States to solar energy systems by the year 2000.

2. As existing family housing units are replaced and as additional units are constructed, passive energy systems should be incorporated into their overall design.

3. Establish an information system for collecting, storing, evaluating, reporting and disseminating technical, environmental and socio-economic data on passive solar technology. This data will enable improvements in system design, the development of appropriate standards and criteria and ultimately, the widespread use of economically competitive and environmentally acceptable passive solar energy systems.

The transition from fossil fuels to alternative energy sources will take a number of decades. The question is, which direction to take and when do you get started?

The energy future of the Nation will depend in part on making the right decisions today. This requires that available alternatives be fully explored, and that consideration be given to energy's relationship to the environment, the economy, housing, transportation and other National priorities.

APPENDIX A - ASSUMPTIONS USED IN THE ANALYSIS

A. Characteristics of a Family Housing Unit

House: 1400 square feet, two story, 3 bedroom, 2-1/2 bath, detached single family unit.

Construction: Exterior walls - standard 2"X4" framing
Windows - single glaze, aluminum frame
Insulation - 6", roof only
Floor - 4" poured concrete
Exterior doors - wood, 1" thick

Heating system: Space heat - gas
Hot water heater - gas

B. GENERAL ASSUMPTIONS

Wind speed: 15 mph

Period of heating analysis: 1-31 January (all zones)

Cost of conventional gas: $3.29/MBtu

Fuel price escalation rate: 14%

C. SAMPLE U-FACTORS USED IN THE ANALYSIS

Item	U-Factor
Windows:	
Single glass	1.13
Double glass	.56
Triple class W/1/2" airspace	.31

Doors:

Exterior wood 1" thick	.64
Exterior wood 2" thick	.43
Exterior wood 2" thick (with storm door)	.24

Insulation:

Sprayed cellulose	3.7 per inch
Fiberglas batt (6")	19

D. CONDUCTANCES AND RESISTANCES OF BUILDING MATERIALS

Gypsum or plaster board - 1/2"	C=2.22
Cement plaster (sand aggregate)	C=6.66
Air space (4" vertical)	a=1.01

CITY- EL PASO, TEXAS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{O}F) average daily max/min	56/31	62/36	68/41	77/49	85/58	94/67	94/69	92/68	87/63	78/52	66/38	57/33	76/50
Degree Days heating base $65^{O}F$	670	458	330	110	0	0	0	0	0	70	390	626	2641
Wind mph	10	11	13	13	12	11	10	10	9	9	10	10	11

CITY- JACKSONVILLE, FLORIDA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{O}F) average daily max/min	66/45	68/47	73/51	79/58	85/65	90/71	91/73	91/73	88/71	80/62	72/51	67/46	79/59
Degree Days heating base $65^{O}F$	331	254	169	23	0	0	0	0	0	16	148	309	1243
Wind mph	8	10	10	9	9	9	8	8	9	9	8	8	9

APPENDIX B - Climatological data - Zone no. 1
[Source: Ref. 21]

CITY- SAN DIEGO, CALIFORNIA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max/min	64/46	65/48	67/50	68/53	70/57	72/60	76/63	77/64	76/62	73/57	71/51	66/47	70/55
Degree Days heating base 65^{o}F	317	255	223	151	97	43	11	7	24	52	147	255	1574
Wind mph	6	6	7	7	8	7	7	7	6	6	5	5	6

CITY- SHREVEPORT, LOUISIANA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max/min	56/40	61/43	68/49	77/57	83/64	91/71	93/74	95/74	89/69	80/57	66/47	58/41	76/57
Degree Days heating base 65^{o}F	550	388	269	57	0	0	0	0	0	45	283	477	2058
Wind mph	11	11	11	11	9	9	8	8	8	9	10	10	10

Climatological data - Zone no. 1

CITY- ALBUQUERQUE, NEW MEXICO

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max / min	46 / 22	52 / 27	60 / 32	69 / 42	79 / 52	89 / 61	92 / 66	89 / 65	82 / 58	71 / 45	57 / 31	47 / 25	69 / 44
Degree Days heating base $65^{o}F$	970	737	589	289	70	0	0	0	10	218	630	899	4389
Wind mph	8	9	10	11	10	10	9	8	9	8	8	7	9

CITY- KANSAS CITY, MO.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max / min	39 / 21	44 / 25	54 / 34	66 / 46	75 / 56	85 / 66	91 / 71	89 / 69	81 / 60	70 / 49	54 / 35	42 / 25	66 / 46
Degree Days heating base $65^{o}F$	1085	878	666	292	111	8	0	0	44	240	621	970	4883
Wind mph	10	11	12	12	11	10	9	9	9	9	11	10	10

Climatological data - Zone no. 2

CITY- LAS VEGAS, NEVADA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max / min	55 / 33	62 / 39	69 / 44	79 / 53	88 / 60	99 / 68	105 / 76	103 / 74	96 / 65	82 / 53	67 / 41	58 / 36	80 / 53
Degree Days heating base $65^{o}F$	653	435	288	92	0	0	0	0	0	61	344	564	2425
Wind mph	7	8	10	10	11	11	10	10	9	8	6	6	9

CITY-SAN FRANCISCO, CALIFORNIA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max / min	55 / 45	59 / 47	61 / 49	62 / 49	63 / 51	65 / 53	64 / 53	65 / 54	68 / 55	68 / 54	64 / 51	57 / 47	63 / 51
Degree Days heating base $65^{o}F$	462	347	317	279	248	180	189	177	110	128	237	406	3069
Wind mph	7	8	9	10	10	11	11	11	9	8	6	7	9

Climatological data - Zone no. 2

CITY- WASHINGTON, D.C.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max/min	44/29	45/29	55/36	65/44	75/55	83/64	86/68	84/67	78/61	67/49	56/39	45/31	65/48
Degree Days heating base $65^{o}F$	893	806	619	323	87	0	0	0	37	237	519	837	4333
Wind mph	11	11	12	11	10	9	9	8	9	9	10	10	10

Climatological data - Zone no. 2

CITY- CHICAGO, ILLINOIS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max / min	33 / 17	35 / 20	45 / 29	58 / 39	70 / 49	80 / 59	85 / 64	83 / 62	76 / 55	64 / 44	48 / 31	35 / 21	59 / 41
Degree Days heating base $65^{o}F$	1243	1087	868	507	229	58	0	0	90	350	765	1147	6310
Wind mph	11	11	12	11	10	9	8	8	9	9	12	11	10

CITY- DENVER, COLORADO

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max / min	42 / 16	45 / 19	51 / 25	61 / 34	69 / 43	81 / 52	87 / 58	85 / 57	77 / 48	66 / 37	53 / 26	45 / 18	64 / 36
Degree Days heating base $65^{o}F$	1125	954	843	525	286	65	5	11	120	425	771	1032	6132
Wind mph	10	10	11	11	10	10	9	9	9	9	10	10	10

Climatological data - Zone no. 3

CITY- OMAHA, NEBRASKA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{O}F) average daily max / min	32 / 14	37 / 18	48 / 28	63 / 42	73 / 52	83 / 62	89 / 68	86 / 65	78 / 56	67 / 44	49 / 29	36 / 19	62 / 41
Degree Days heating base $65^{O}F$	1302	1092	831	389	175	32	0	5	88	331	783	1166	6160
Wind mph	12	12	13	14	12	11	9	10	10	10	12	11	11

CITY- PORTLAND, OREGON

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{O}F) average daily max / min	44 / 35	50 / 38	56 / 41	62 / 45	69 / 50	73 / 54	79 / 58	79 / 58	73 / 54	64 / 49	53 / 42	47 / 38	62 / 47
Degree Days heating base $65^{O}F$	791	613	515	347	199	70	13	14	85	280	534	701	4143
Wind mph	10	9	8	7	6	6	7	7	6	6	8	10	8

Climatological data - Zone no. 3

CITY-ALBANY, NEW YORK

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max	31	32	42	56	69	79	83	81	73	62	47	34	57
min	14	14	24	35	46	55	60	58	50	40	31	19	37
Degree Days heating base $65^{o}F$	1318	1217	989	597	246	50	0	24	139	443	780	1197	6962
Wind mph	10	11	11	11	9	8	7	7	7	8	9	9	9

CITY-BILLINGS, MONTANA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max	32	36	44	58	68	77	88	88	73	61	45	36	59
min	13	16	24	34	44	52	59	56	47	38	27	18	36
Degree Days heating base $65^{o}F$	1305	1125	958	564	304	119	8	20	194	497	876	1172	7106
Wind mph	13	12	12	12	11	11	10	10	10	11	12	13	11

Climatological data - Zone no. 4

CITY- BOISE, IDAHO

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{O}F) average daily max/min	35/20	42/26	52/31	62/38	71/45	79/51	91/59	88/57	77/48	65/40	49/30	38/24	62/39
Degree Days heating base $65^{O}F$	1169	895	719	453	249	92	0	0	135	389	762	1054	5890
Wind mph	0	10	11	11	10	9	9	9	9	9	9	9	9

CITY- PORTLAND, MAINE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{O}F) average daily max/min	31/11	32/11	41/22	52/32	63/42	73/51	79/57	77/55	70/47	60/37	47/28	35/16	55/34
Degree Days heating base $65^{O}F$	1373	1257	1039	693	394	117	15	56	199	515	825	1237	7681
Wind mph	10	10	10	10	9	8	8	8	8	9	9	9	9

Climatological data - Zone no. 4

CITY-FARGO, NORTH DAKOTA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max/min	17/-3	21/1	35/16	53/31	67/43	77/53	84/58	82/56	71/47	57/35	36/19	22/4	52/30
Degree Days heating base $65^{o}F$	1795	1567	1231	687	338	101	25	41	215	586	1122	1615	9274
Wind mph	14	14	14	16	15	13	12	12	13	14	15	14	14

CITY- DULUTH, MINNESOTA

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Temp (^{o}F) average daily max/min	17/-1	21/2	31/13	46/28	60/39	70/49	77/56	75/55	65/46	53/35	34/20	21/5	47/29
Degree Days heating base $65^{o}F$	1758	1562	1327	846	474	178	56	91	298	651	1140	1656	9957
Wind mph	13	13	13	15	14	12	11	11	12	13	14	13	13

Climatological data - Zone no. 5

APPENDIX C - HEAT LOSS/HEAT GAIN CONSIDERATIONS

A. SOLAR HEAT GAIN

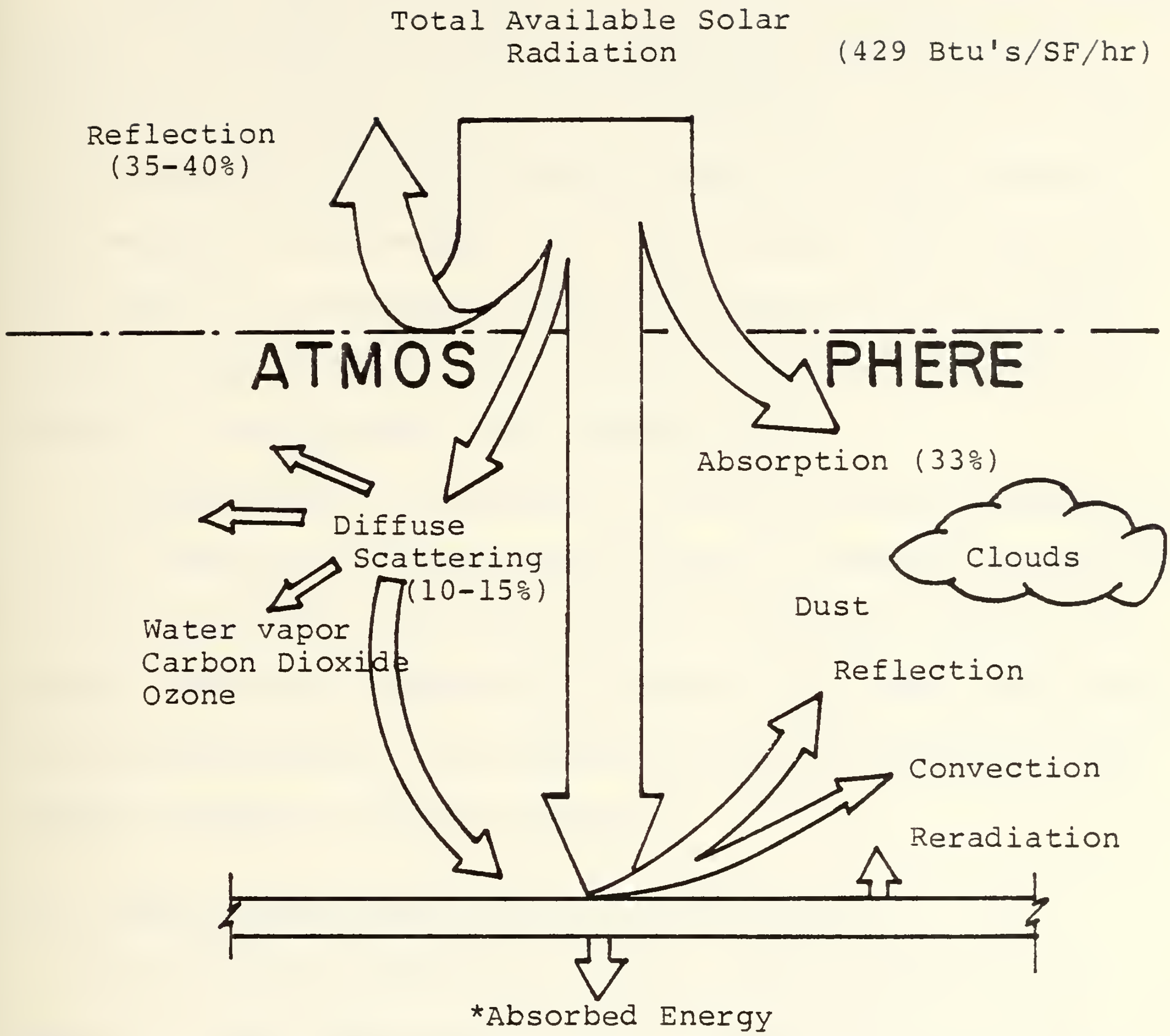
The available radiation from the sun at a point outside the earth's atmosphere is approximately 429 Btu's/SF per hour. Of this total available energy, 35-40% of it (150 to 170 Btu's/SF/hr) is reflected back into space.

Of the remaining energy transmitted, approximately 15% of it is scattered or diffused by water vapor, carbon dioxide and ozone. This amounts to approximately 65 Btu/s/SF/hr.

Clouds and dust are capable of scattering or reflecting approximately 33% of the incoming energy. This could amount to as much as 92 Btu's/SF/hr.

Therefore, on a cloudy day, as much as 100% of the energy available will come from diffuse radiation, or the energy scattered by the atmosphere and redirected to the earth's surface.

An equally important factor in determining available solar heat is the distance the energy must travel through the atmosphere. At 12 o'clock noon, the distance it travels is at a minimum, but as the sun moves closer to the horizon, the distance the radiation must pass through lengthens, which results in a decreasing amount of solar radiated energy being intercepted by a structure. Finally, at sundown the radiated



*Determined by surface texture, incident angle of the sun's rays, surface color, and the distance the radiation travels in the atmosphere.

FIGURE C-1 Available solar energy
[Source: Ref. 7]

energy is sufficiently low to enable us to look directly at the sun. (See Appendix D.)

Another important factor which must be taken into consideration is the angle at which the radiated energy strikes a structure's surface, the angle of incidence. If the surface is perpendicular to the incoming energy, it will intercept 100 percent of the energy. As the incident angle increases, the amount of intercepted energy decreases until at angles greater than 90° only a very small percent of the radiated energy is intercepted. (See Appendix F.)

Closely tied to the amount of radiated energy intercepted, is the amount of radiated energy that is reflected or absorbed by that intercepting surface due to its surface texture or color. The more polished the surface, the greater the amount of reflected energy. The darker the color, generally, the greater amount of energy absorbed.

B. THEORY UNDERLYING HEAT LOSS CALCULATIONS

The overall coefficient of heat transmission U is the amount of heat expressed in BTU's transmitted in one hour per square foot of wall, floor, roof, or ceiling for a difference in temperature of 1 degree F between the air on the inside and that on the outside of the wall, floor, roof or ceiling.

It has been determined that heat transfer is retarded by the following elements comprising a wall, roof or other building section taken in order from outside air to inside air;

(1) the resistance of a film of air on the outside (which is generally considered to be exposed to wind velocities averaging 15 miles per hour), (2) the resistance of each layer of building materials forming the structural section; (3) the resistance of each measurably enclosed air space formed within the building section; and (4) the resistance of the surface film of air on the inner face (which is considered to be in still air).

The overall coefficient of heat transmission U is the reciprocal of the sum of the foregoing resistances.

C. INSULATION AND HEAT FLOW TERMS

R - This is the resistance to heat flow or the reciprocal of U sometimes expressed as 1/U. Insulation is often labled in R values. R values are additive, double the thickness of insulation and the R value doubles.

C - A unit of thermal conductance. The amount of heat per hour (Btuh) transmitted from surface to surface of one square foot of material or a combination of of materials for each degree F of temperature difference between the two surfaces.

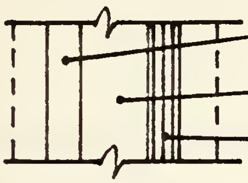
f - Film or surface conductance. Btuh transmitted from one square foot of a surface to the air surrounding the surface for each degree F temperature difference. The symbols f_i and f_o designate inside and outside conductances.

1/f - Film or surface resistance. The resistance to heat flow of an air film adjacent to a surface.

a - Thermal conductance of an airspace. The Btuh, transmitted across an airsapce on one square foot for each degree F temperature difference.

1/a - Air space resistance to heat flow.

2'X4" Exterior Wall



$\frac{7}{8}$ " Stucco C_1=6.66

$3\frac{1}{2}$ " Air Space a=1.01

$\frac{1}{2}$ " Gyp Board C_2=2.22

$$f_o = \text{15 MPH Wind} = .17$$

$$f_1 = \cancel{0}\ \text{MPH} = .68$$

$$U_t = \frac{1}{\frac{1}{f_o} + \frac{1}{c_1} + \frac{1}{a} + \frac{1}{c_2} + \frac{1}{f_1}}$$

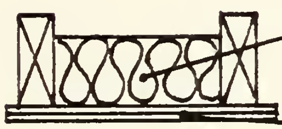
$$U_t = \frac{1}{\frac{1}{.17} + \frac{1}{2.22} + \frac{1}{.68} + \frac{1}{1.01} + \frac{1}{6.66}}$$

$$U_t = \frac{1}{5.88 + .45 + 1.47 + 1.0 + .15}$$

$$U_t = \frac{1}{8.95}$$

$$U_t = .1117\ \text{Btu/Hr/SF/}^{o}\text{F}$$

Ceilings



6" Batt Insulation R=19

$\frac{1}{2}$ " Gypsum Board C=2.22

$$U_t = \frac{1}{\frac{1}{.17} + \frac{1}{2.22} + \frac{1}{19} + \frac{1}{.17}}$$

$$U_t = \frac{1}{5.88 + .45 + 5.88 + .053}$$

$$U_t = \frac{1}{12.26}$$

$$U_t = .0815\ \text{Btu/Hr/SF/}^{o}\text{F}$$

Floor Slab (4" Concrete)

$$HL_{edge} = \text{Perimeter X Heat Loss Factor (F)}$$

$$HL_e = (2 \times 22' + 2 \times 31'\text{-}6")\ (1)$$

$$HL_e = 107\ \text{Btu/HR/}^{o}\text{F}$$

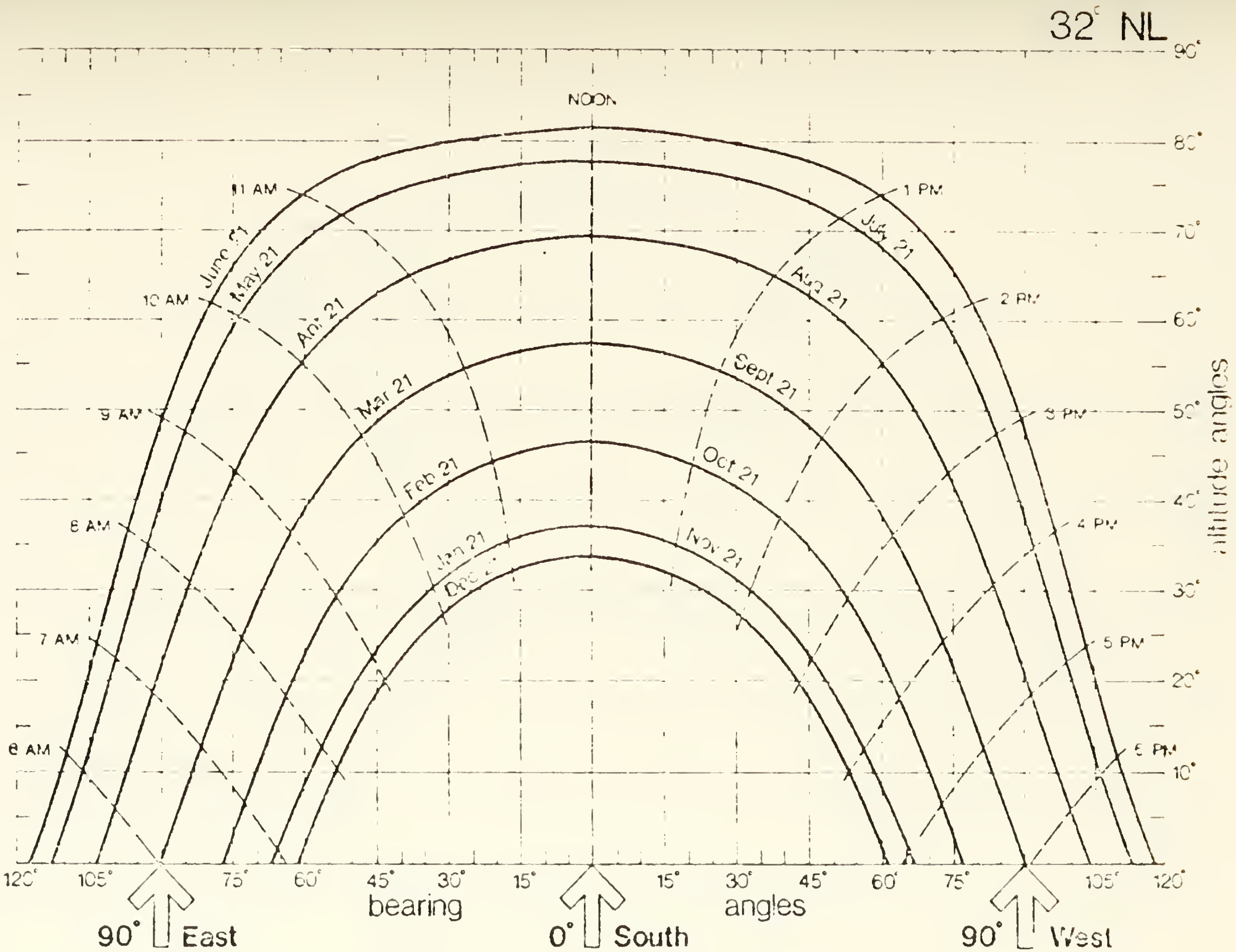
Heat Loss (Sample)

Item	A		x	U	=	Btu/HR/ ^{o}F
Exposed Wall (Ext)	1621.5	SF	x	.1117	=	181.12
Roof	737	SF	x	.0815	=	60.06
Door (Ext)	20	SF	x	.64	=	12.80
Exposed Glass	102.53	SF	x	1.13	=	115.86
Floor Slab (Edge)	107	LF	x	1	=	107.00
Infiltration	11792	CF	x	.018*	=	212.25
				HL	=	689.09

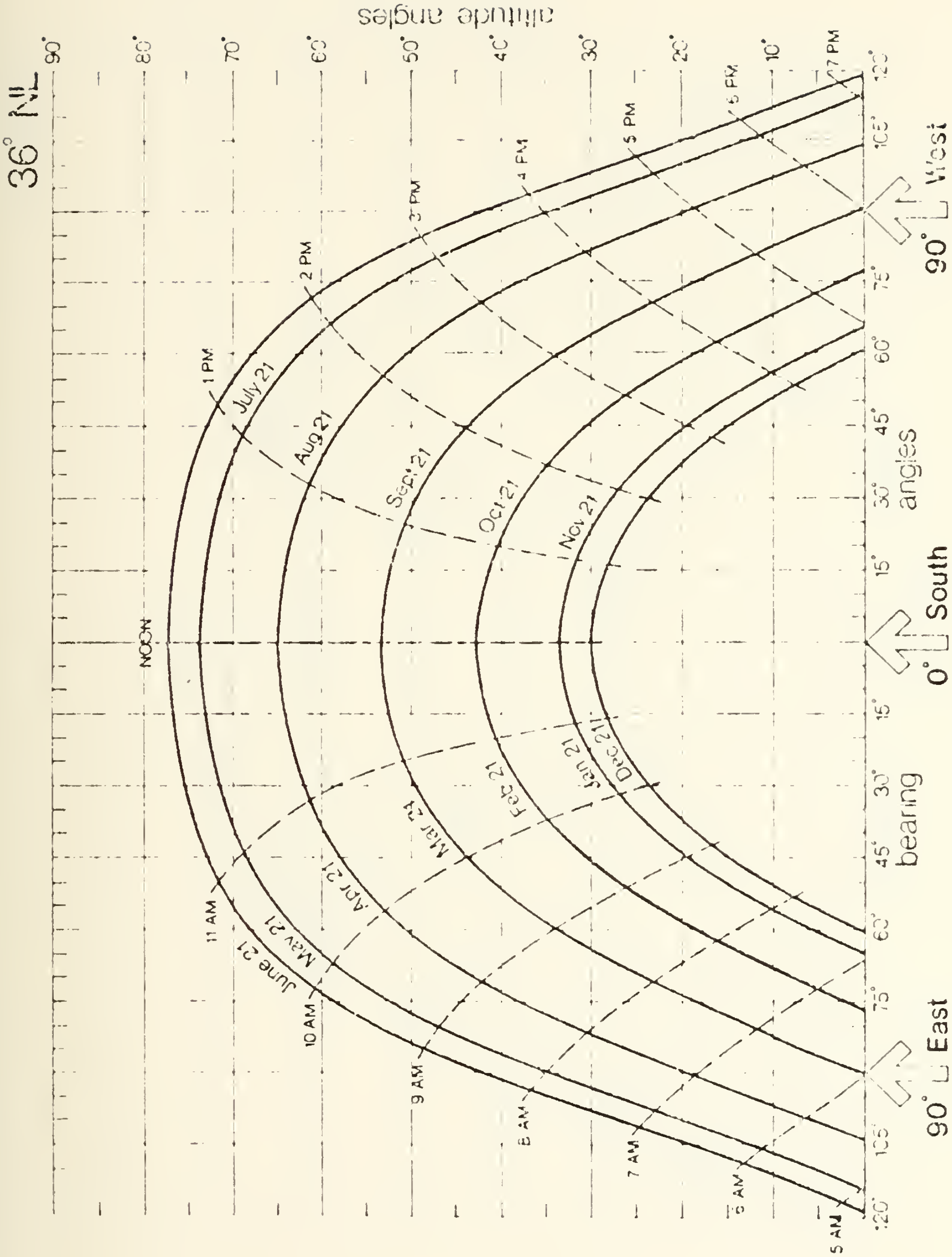
$$HL_t = 689.09 \times (\Delta T) \times 24\ \text{hrs}$$

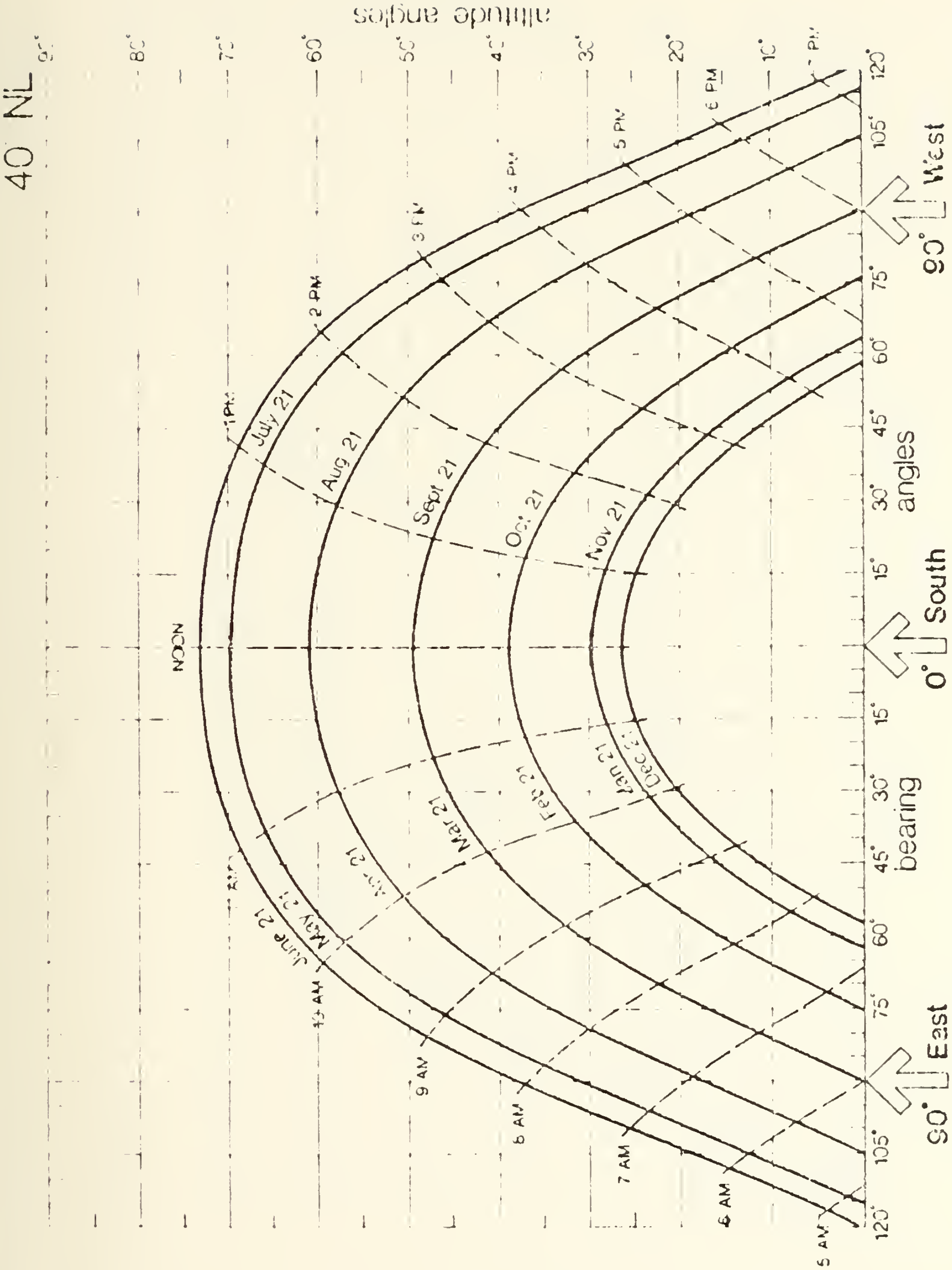
$$HL_t = 16538.16\ (\Delta T)$$

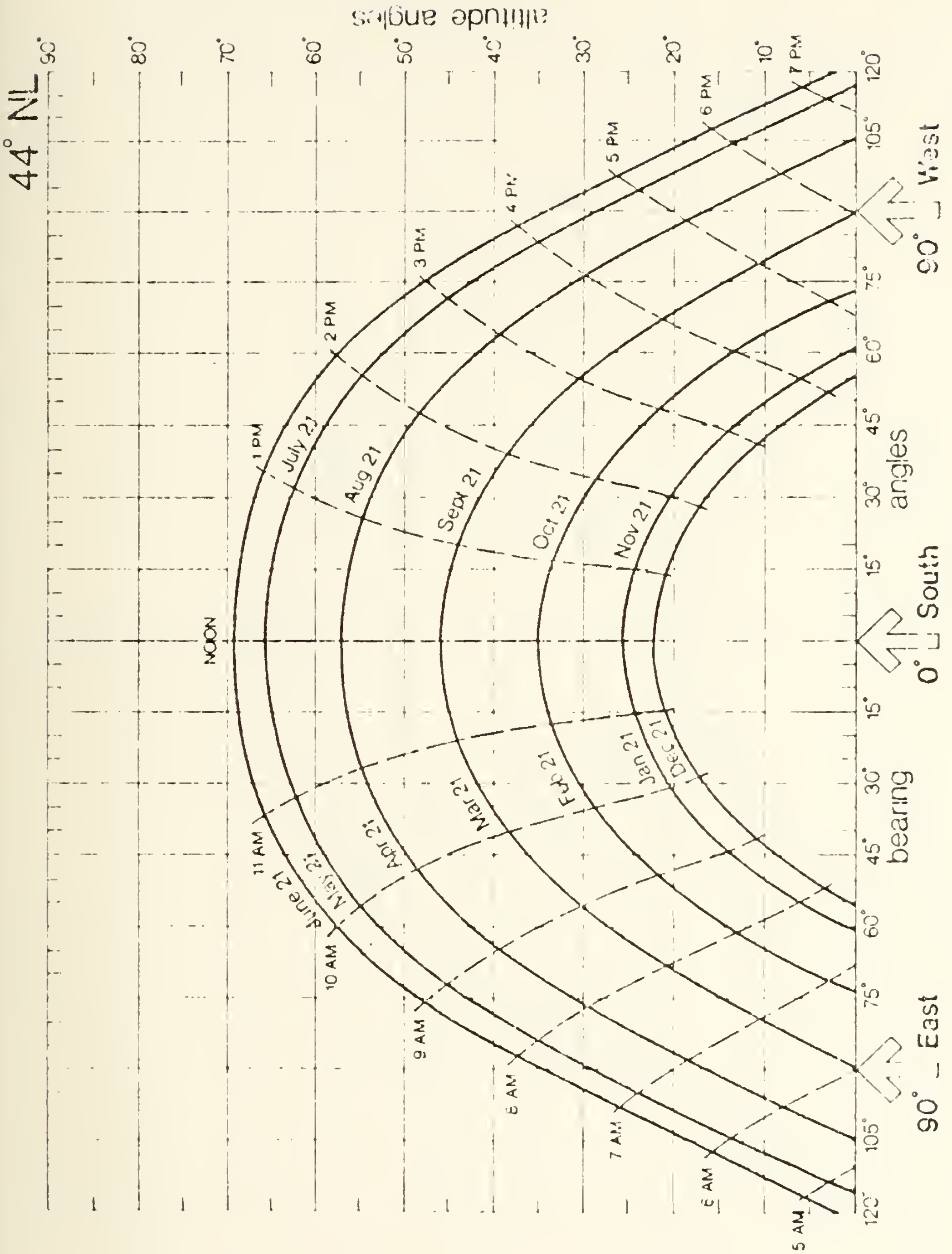
*A constant derived by multiplying the specific heat of air by its density.

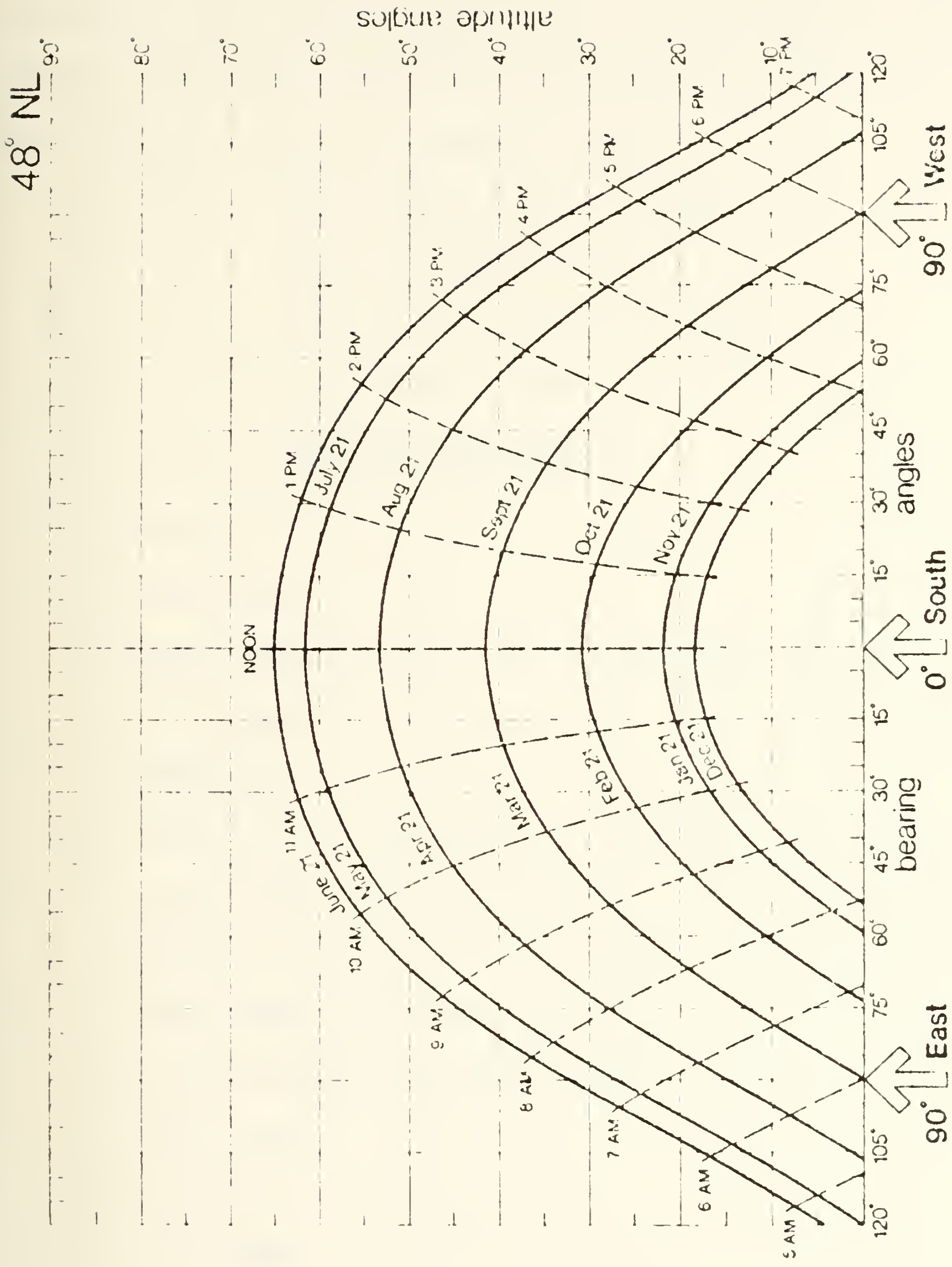


APPENDIX D. Sun charts for 32°, 36°, 40°, 44°, and 48° north latitudes
[Source: Ref. 2]


36° NL
altitude angles
90°
80°
70°
60°
50°
40°
30°
20°
10°
bearing angles
120°
105°
75°
60°
45°
30°
15°
90° East
0° South
90° West
NOON
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21


40° NL
altitude angles
bearing angles
90° East
0° South
90° West
NOON
June 21
May 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
5 AM
6 AM
7 AM
8 AM
9 AM
2 PM
3 PM
4 PM
5 PM
6 PM
120°
105°
75°
60°
45°
30°
15°
80°
70°
60°
50°
40°
30°
20°
10°


44° NL
altitude angles
90°
80°
70°
60°
50°
40°
30°
20°
10°
bearing angles
120°
105°
90° East
75°
60°
45°
30°
15°
0° South
15°
30°
45°
60°
75°
90° West
105°
120°
NOON
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21


48° NL
altitude angles
90°
80°
70°
60°
50°
40°
30°
20°
10°
NOON
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
June 21
May 21
Apr 21
Mar 21
Feb 21
Jan 21
Dec 21
July 21
Aug 21
Sept 21
Oct 21
Nov 21
bearing angles
120°
105°
90° East
75°
60°
45°
30°
15°
0° South
15°
30°
45°
60°
75°
90° West
105°
120°

APPENDIX E-FORMULAS FOR DETERMINING SPECIFIC AZIMUTHS AND ALTITUDES

For those who have a special need of knowing accurately the Azimuth and Altitude for a particular date or hour not readily obtainable from the solar charts, the following formulas and information are provided:

1. $\sin h = \sin L \sin d + \cos L \cos d \cos t$
2. $\sin z = \sin t \cos d \sec h$
3. $\cos t = -\tan L \tan d$ (when $h = 0^{\circ}$)
4. $\cos z = \sin d \sec L$ (when $h = 0^{\circ}$)
5. $\cos t = \dfrac{\sin h - \sin L \sin d}{\cos L \cos d}$

in which:

L = latitude

d = declination; i.e., the angle between a line connecting the centers of the sun and earth and the plane of the equator.

t = time of day expressed in degrees. Since there are 24 hours and also 360° degrees in one revoluation of the earth, 1 hour = 15°, 1 minute = 15' and 1 second = 15". This angle is always measured from the noon position of the sun, therefore noon = 0°, 10 am = 30°, 4 pm = 60°, etc.

z = Azimuth

h = Altitude

Declination of the sun varies for each day of the year from approximately $23^{\circ}27'$ north to $23^{\circ}27'$ south.

When the declination is North, it is considered plus (+), then South, minus (-). The precise declination as it varies for each year can be found in the American National Almanac issued annually by the U. S. Naval Observatory, Washington D.C.

Example: The Azimuth and Altitude of the sun for 2 pm, May 15, at Latitude 42°N.

$L = 42^\circ$

$d = 18^\circ 40'$

$t = 30^\circ$

from 1. $\sin h = \sin 42^\circ \sin 18^\circ 40' + \cos 42^\circ \cos 18^\circ 40' \cos 30^\circ$

$$= .670 \times .320 + .745 \times .950 \times .865$$

$$= .215 + .612 = .827$$

$$h = 56^\circ$$

from 2. $\sin z = \sin 30^\circ \cos 18^\circ 40' \sec 56^\circ$

$$= .500 \times .950 \times 1.79$$

$$z = 59^\circ \text{ or } 121^\circ$$

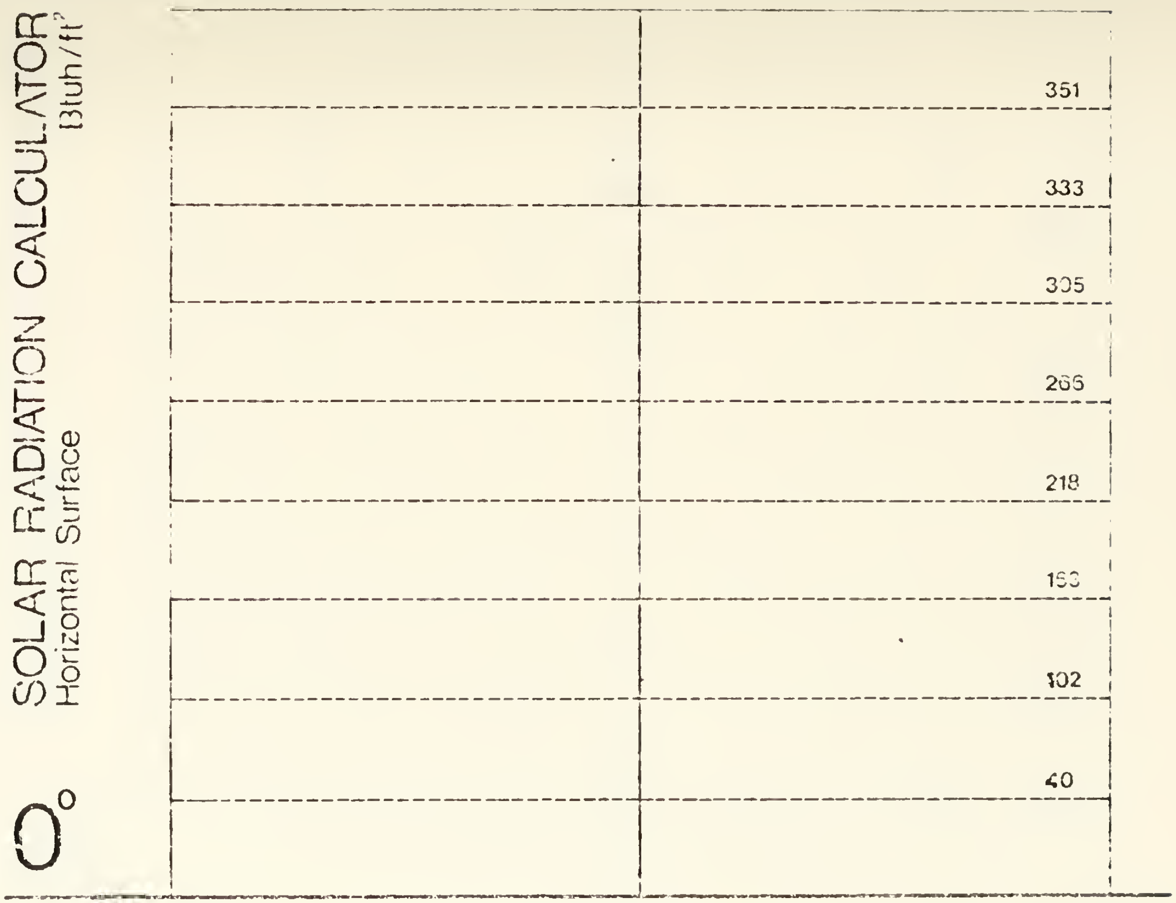
The hour of sunrise (or sunset) and its azimuth may be found from equations 3 and 4.

Local sun time may be found from equation 5.

Sun time is the hour of day as determined by the position of the sun with relation to its noon meridan. Since standard time (clock time) is based on the suntime at the center of each hourly time zone, sun time may vary as much as 1/2 hour from standard time depending on the locality.

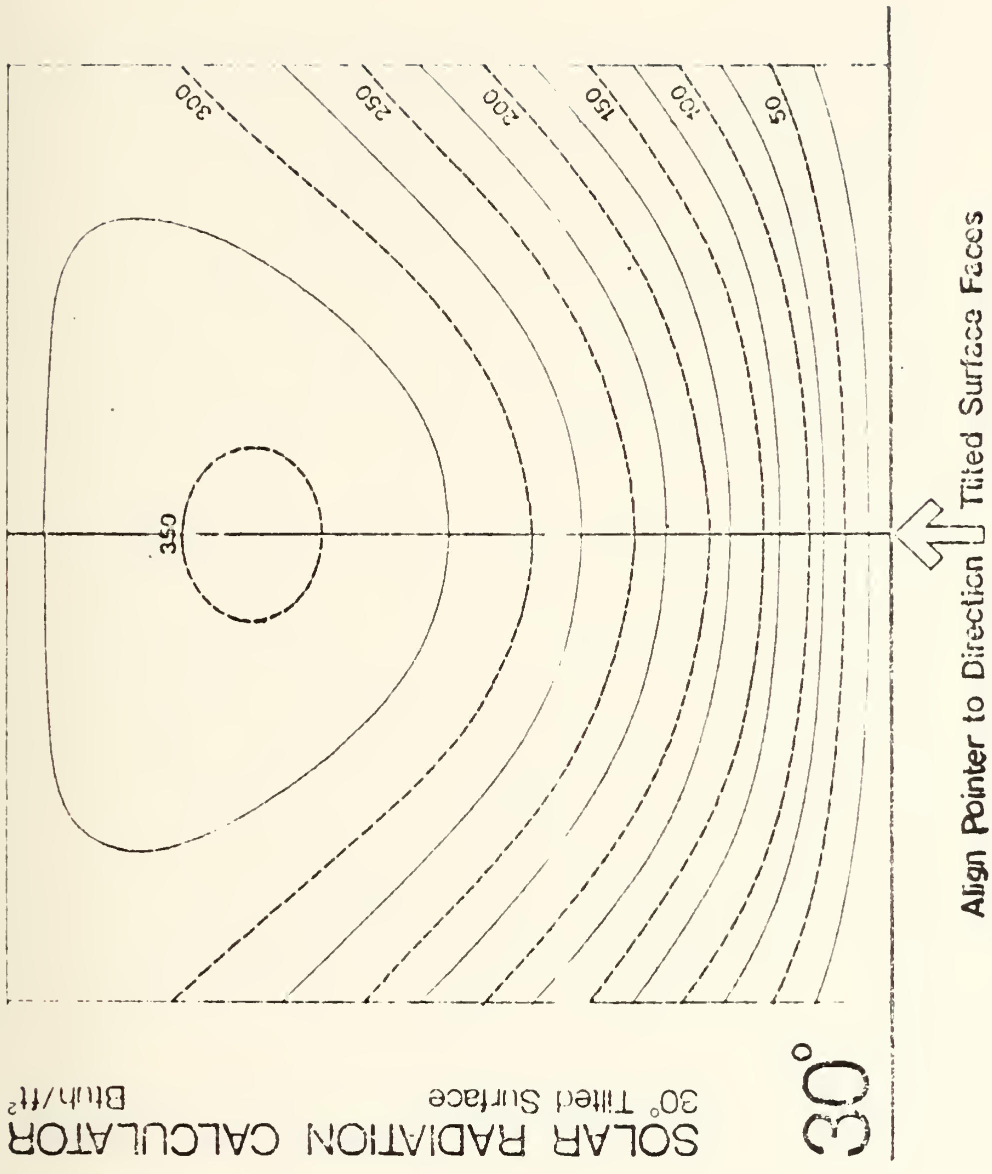
Table E-1 DECLINATION OF THE SUN-NEAREST TO 5'
[Source: Ref. 22]

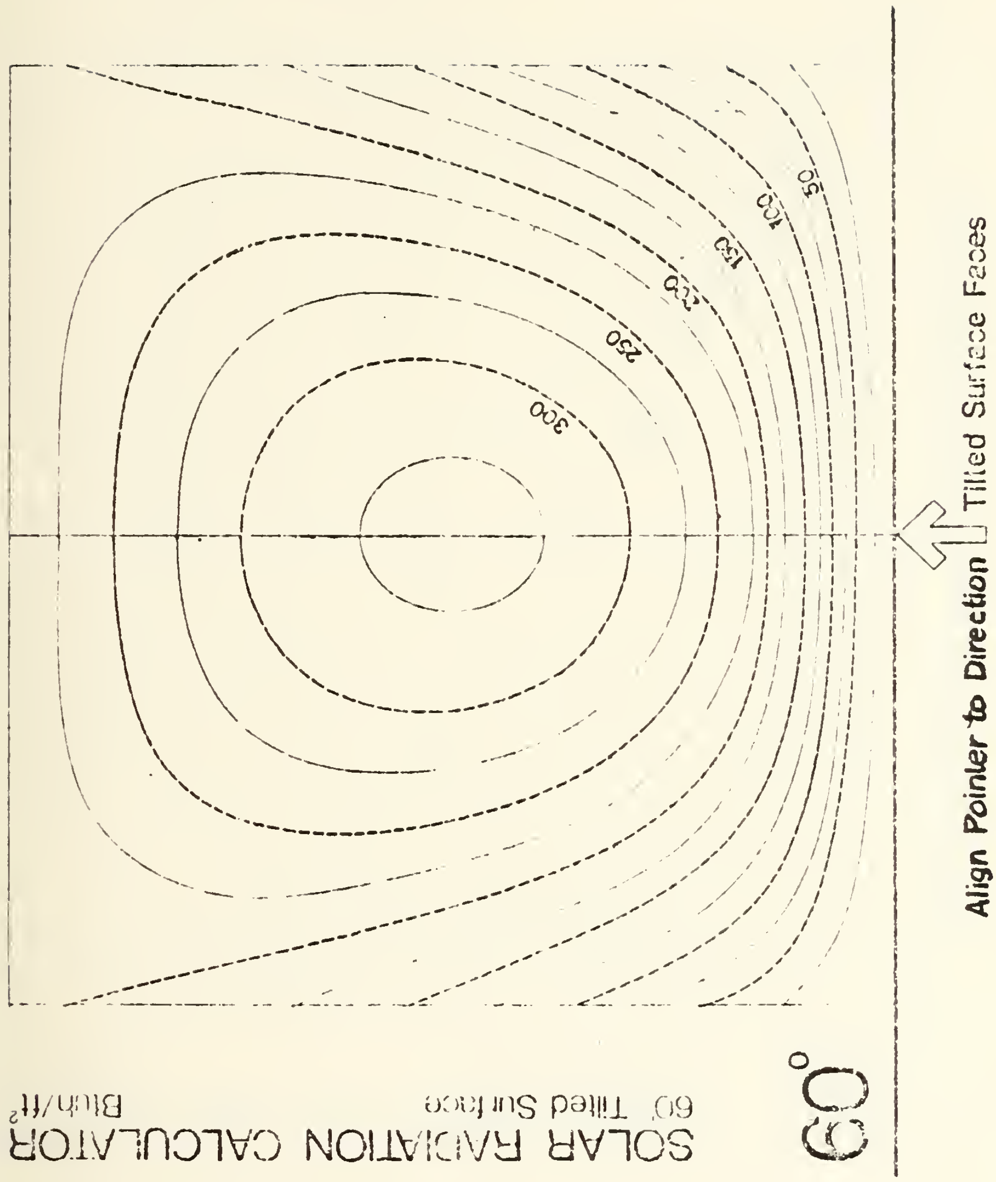
DATE	DECLINATION	DATE
Jun 22	$+ 23^{\circ} - 30'$	
15	$+ 23^{\circ} - 15'$	Jun 29
8	$+ 22^{\circ} - 45'$	Jul 6
1	$+ 21^{\circ} - 55'$	13
May 25	$+ 20^{\circ} - 50'$	20
18	$+ 19^{\circ} - 25'$	27
11	$+ 17^{\circ} - 40'$	Aug 3
4	$+ 15^{\circ} - 45'$	10
Apr 26	$+ 13^{\circ} - 20'$	18
19	$+ 11^{\circ} - 0'$	25
12	$+ 8^{\circ} - 30'$	Sep 1
5	$+ 5^{\circ} - 55'$	8
Mar 28	$+ 2^{\circ} - 50'$	16
21	$0^{\circ} - 0'$	23
14	$- 2^{\circ} - 50'$	Oct 1
7	$- 5^{\circ} - 35'$	8
Feb 28	$- 8^{\circ} - 15'$	15
21	$- 10^{\circ} - 50'$	22
14	$- 13^{\circ} - 15'$	29
7	$- 15^{\circ} - 30'$	Nov 5
Jan 31	$- 17^{\circ} - 30'$	12
24	$- 19^{\circ} - 20'$	19
17	$- 20^{\circ} - 50'$	26
10	$- 22^{\circ} - 0'$	Dec 3
3	$- 22^{\circ} - 50'$	10
Dec 27	$- 23^{\circ} - 20'$	17
	$- 23^{\circ} - 30'$	22



APPENDIX F SOLAR RADIATION CALCULATORS FOR 0°, 30°, 60°, AND 90° TILTED SURFACES

[Source: Ref. 2]


SOLAR RADIATION CALCULATOR
30° Tilted Surface
Btuh/ft²
30°
300
250
200
150
100
50
350
Align Pointer to Direction Tilted Surface Faces

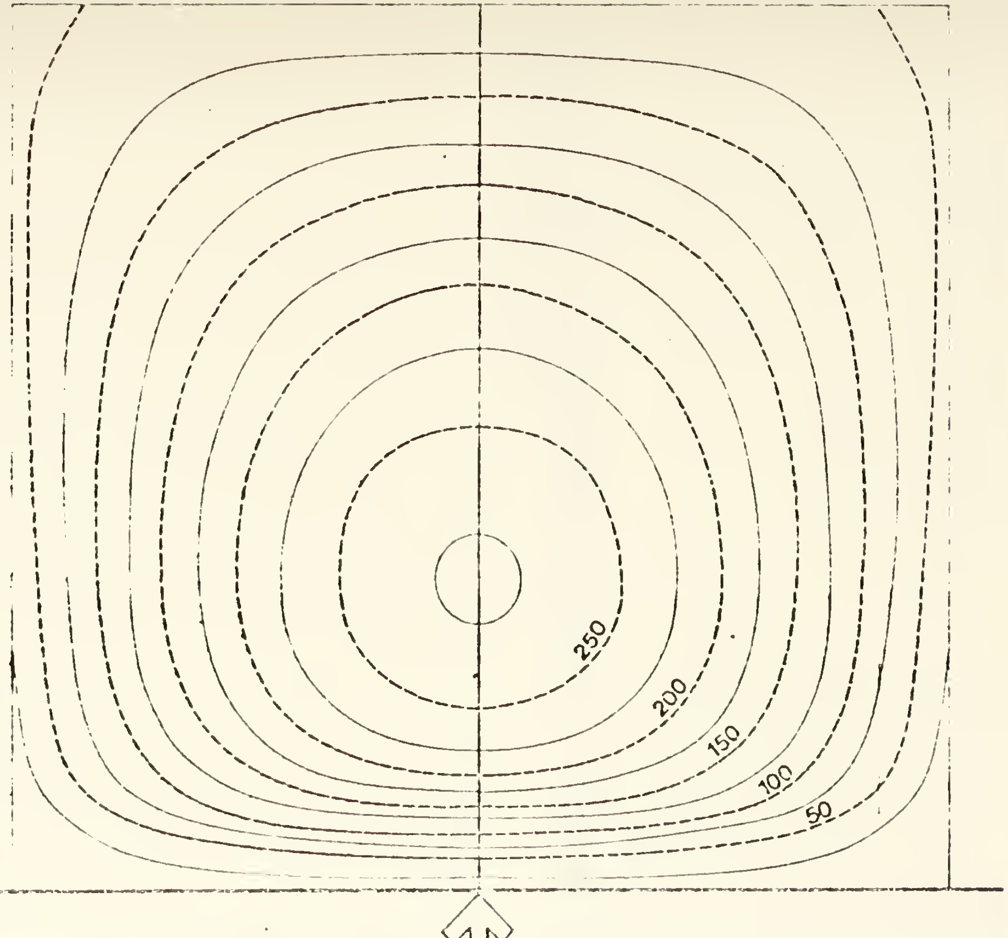

SOLAR RADIATION CALCULATOR
60° Tilted Surface
Btuh/ft²
60°
300
250
200
150
100
50
Align Pointer to Direction Tilted Surface Faces

SOLAR RADIATION CALCULATOR

Vertical Surface

Btuh/ft²

90°



Align Pointer to Direction Vertical Surface Faces

APPENDIX G - WIND VELOCITY FACTORS

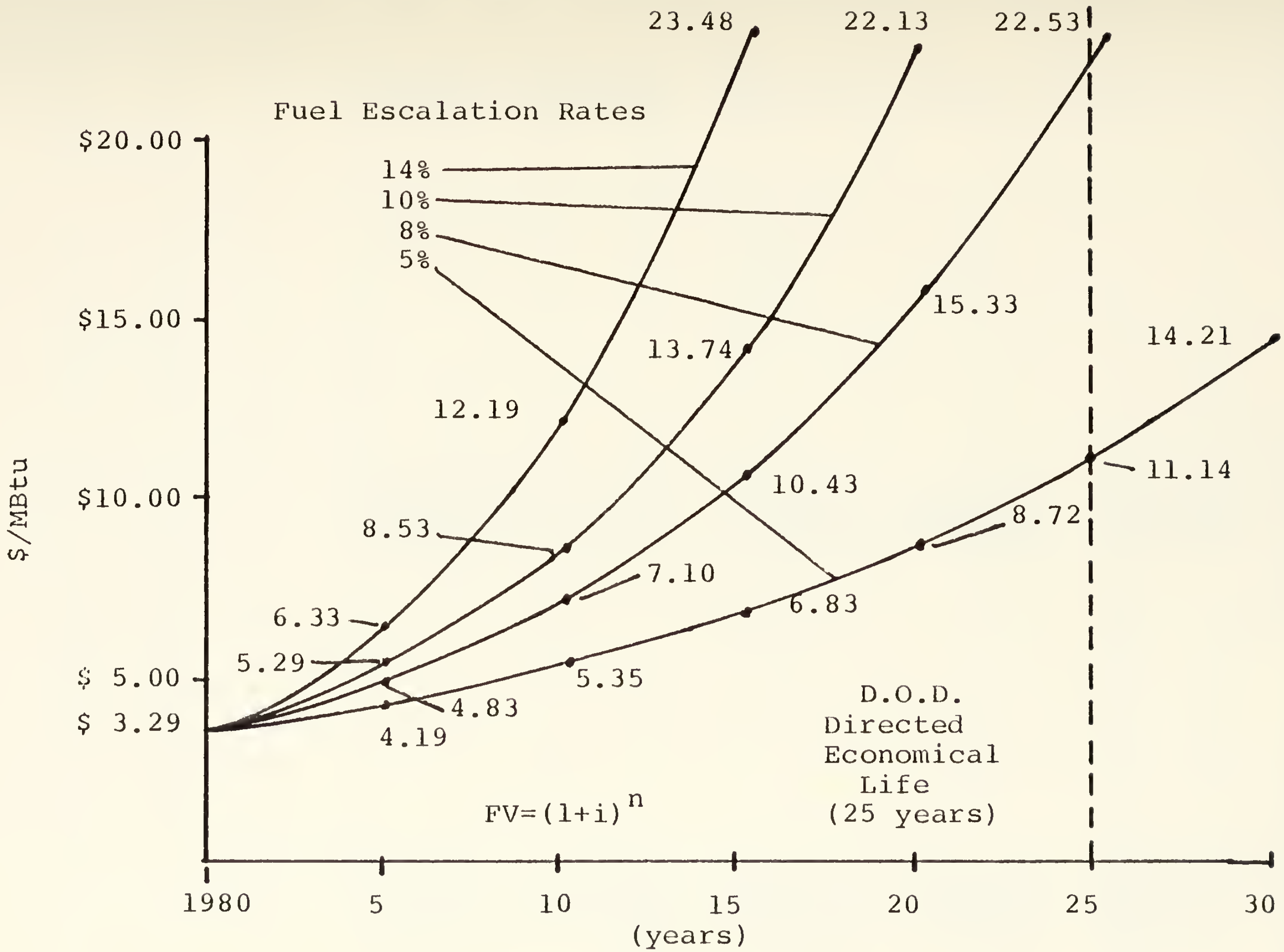
[Ref. 2]

Wind Velocity (mph)	Factor (fw)
0-15	1.00
20	1.04
25	1.08
30	1.12
35	1.16
40	1.20

Total Heat Loss Adjusted for Wind - Calculated Heat Loss (HLt) X (Fw)

APPENDIX H - ENERGY CONVERSION FACTORS
(Source: Ref. 23]

Purchased electricity	11,600 Btu/Kwh
Distillate fuel oil	138,700 Btu/Gallon
Natural gas	1,031,000 Btu/1000 Cubic Feet
LPG, Propane, Butane	95.000 Btu/Gallon
Bituminous coal	24,580,000 Btu/Short Ton
Anthracite coal	28,3000,000 Btu/Short Ton
Purchased steam	1,390 Btu/pound



APPENDIX I PROJECTED FUEL PRICES - NATURAL GAS

APPENDIX J - DEPARTMENT OF DEFENSE 10% DISCOUNT RATE CHART
[Source: Ref. 17]

Economic Life Years	One Time Cost Factors	Recurring Benefits/Costs Factors
1	0.954	0.954
2	0.867	1.321
3	0.788	2.609
4	0.717	3.326
5	0.652	3.977
6	0.592	4.570
7	0.538	5.108
8	0.489	5.597
9	0.445	6.042
10	0.405	6.447
11	0.368	6.815
12	0.334	7.149
13	0.304	7.453
14	0.276	7.729
15	0.251	7.980
16	0.228	8.209
17	0.208	8.416
18	0.189	8.605
19	0.172	8.777
20	0.156	8.933
21	0.142	9.074
22	0.139	9.203
23	0.117	9.320
24	0.107	9.427
25	0.097	9.524

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A study of passive solar space heating techniques applied to family housing units within the continental United States.